TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

NIKO NIEMELÄ

INFORMATION FLOW MANAGEMENT IN CUSTOMER-ORIENTED SHEET METAL PRODUCTION

Master of Science Thesis

Examiners:
Professor Minna Lanz
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Examiners and topic approved by the Faculty Council of the Faculty of Engineering Sciences on 26th April 2017

ABSTRACT

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The research problem in this thesis is related to the sheet metal NC process and its requirements from the point of view of data transferring. The aim is to map the current state of sheet metal production of the company with its information flows, and to find the potential problems associated with it. The company is known to be implementing a new CAD design environment and the product information management system. In addition, the company's intention is to introduce a new laser machine that will require new software to support nesting. This change has progressed to the point where the current process needs to be mapped and the related information flows identified.

The research is limited to examining the sheet metal process from design to production, focusing on the programming department. The focus will be on identifying the information related to the programming department and in the stages of the production process where programming is associated. A qualitative case study, in which the interviews of the target persons have been conducted as semi-structured, is used as a research method. The knowledge of sheet metal production is expanded with a literature study that provides the basics needed to conduct a case study.

For the basis of the case study, the process flow charts were developed based on the most important aspects of the sheet metal process of the company. These process flow charts present the most important work phases and the related information flow. The potential problem and challenging areas were identified based on the created process charts. These are presented in a thematic way with the aim of providing development suggestions.

The challenges identified in the research were related to potential errors in the information flows as well as human based errors, to revision management, and to avoiding manual and non-productive work. In addition to this, challenges were found in the extra optimization of programming and the programming of press brakes or its absence.

TIIVISTELMÄ

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Avainsanat: informaatio virrat, nc-prosessi, nc-ohjelmointi, nestaus, ohutlevy

Tämän työn tutkimusongelma liittyy ohutlevytuotannon NC-prosessiin ja sen vaatimuksiin tiedonsiirrollisesta näkökulmasta. Tarkoituksena on kartoittaa yrityksen ohutlevytuotannon nykytila, löytää työvaiheiden väliset informaatiovirrat sekä näihin liittyvät mahdolliset ongelmakohdat. Yritys on ottamassa käyttöön uutta CAD-suunnitteluympäristöä sekä tuotetiedon hallinnan järjestelmää. Lisäksi tarkoituksena on käyttöönottaa uusi laser levytyöstökeskus, joka tulee edellyttämään uutta ohjelmistoa nestauksen tueksi. Tämän muutoksen johdosta olemassa oleva prosessi on kartoitettava ja siihen liittyvät tietovirrat tunnistettava.

Tutkimus on rajattu tarkastelemaan ohutlevyprosessia suunnittelusta tuotantoon, keskittyen ohjelmointiosaston ympärille. Painopiste tulee olemaan ohjelmointiosastoon sidonnaisen informaation tunnistamisessa sekä ohjelmointiin sidonnaisissa tuotannon työvaiheissa. Tutkimusmenetelmänä käytetään laadullista tapaustutkimusta, jossa kohdehenkilöiden haastattelut on suoritettu puolistrukturoituina. Tietämystä ohutlevytuotannosta laajennetaan kirjallisuustutkimuksella, jolla luodaan tarvittava pohjatieto tapaustutkimuksen suorittamiseksi.

Tapaustutkimuksen pohjalta muodostettiin yrityksen ohutlevyprosessin keskeisimmistä osa-alueista prosessikaaviot, joissa esitellään keskeisimmät työvaiheet sekä niihin sidonnaiset informaatiovirrat. Luotujen prosessikaavioiden pohjalta etsittiin prosessille mahdolliset ongelmakohdat ja haastealueet. Havaitut haasteet on esitelty teemoittain ja niihin liittyen on pyritty antamaan mahdollisia kehitysideoita.

Tutkimuksessa havaitut haastealueet liittyivät: informaatiovirtojen mahdollisiin virhetilanteisiin, ihmisen aiheuttamiin virhetilanteisiin, revision hallintaa sekä manuaalisen ja ei-tuottavan työn välttämiseen. Tämän lisäksi haasteita löytyi ohjelmoinnin ylimääräisestä optimoinnista sekä ohutlevyn särmäykseen liittyvästä ohjelmoinnista tai sen olemattomuudesta.

PREFACE

This master’s thesis was written in collaboration with SeaKing Oy and I would like to thank for the opportunity of implement the project into sheet metal production. Special thanks to my supervisor Vesa Jumppanen and Managing Director Pentti Aalto who made this all possible. In addition, I would like to thank the examiners, Professor Minna Lanz and Professor Kalevi Huhtala, as well as all the interviewees and the people who showed support. You made everything possible.

Studying in TUT has expanded my understanding of technology but it has also brought me many perfect friends. I would like to thank all the students for the shared experiences and adventures over the years. Without you, studying there would have been nothing. All this will end, but the adventures will continue for a long time.

Special thanks go to my dear wife Essi and to my family, you have supported me in everything.

This situation is complemented by a Latin statement,

”Potius sero quam numquam”

- Better late than never.

Helsinki 16.11.2017

Niko Niemelä

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

BOM	Bill of Materials
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
DXF	Drawing Exchange Format
ERP	Enterprise Resource Planning
MCU	Machine Control Unit
MES	Manufacturing Execution System
MIG	Metal-arc inert gas welding
MRP	Material Requirement Planning
MRP II	Manufacturing Resource Planning
NC	Numerical Control
PDM	Product Data Management
TIG	Tungsten inert gas welding

1. INTRODUCTION

This study focuses on the sheet metal design and production of the catering furniture manufacturer in the shipbuilding industry. The company's production is based on customer-tailored products where orders vary depending on the customer. Despite the high production volume, the bath sizes of the products to be manufactured are small, which is a challenge for the manufacturing of sheet metal products.

The aim of this study is to map the current state of the company's production design, programming, and manufacturing process, and based on the mapping to provide process diagrams of the key areas with related information flows. The information flows are studied from the sheet metal process point of view, more precisely from the viewpoint of the NC process where the information is tied to the programming department and to the requirements of the laser cutting.

1.1 Background

SeaKing designs and supplies complete catering systems for cruise ships, based on a long experience and deep knowledge of the cruise ships catering operations. SeaKing is a competitive and a reliable partner, located close to the owners and shipyards, with operations in Europe and North America. The catering systems consist of all supplies that are necessary in preparing, storing, and serving food and refreshment. All this is implemented effectively.

SeaKing was founded over 30 years ago, in 1985, and is the market leader with over 130 completed cruise vessels. The company has focused only on cruise vessel catering systems and supplies catering equipment to all major shipyards and owners. The sales, design, project, and after sales departments are located in Helsinki, whereas the production and production design facilities are located in Poland. A typical project covers the whole process from concept design to installation depending on customer needs. A typical project takes up to several years, depending on the scope of the delivery.

SeaKing manufactures customer-oriented products to meet the needs of the customers. These products consist partly of both the standardized modules of equipment and the customized products. The ability to produce tailor-made products with short delay creates the company's competitive advantage. (SeaKing 2017.)

1.2 Research problem, targets and limits

The research problem with this thesis is formed around NC programming. The target company has acquired a third laser cutting machine that differs from the previous two. The aim is to clarify the situation of the current sheet metal process and to evaluate how the new equipment fits into the existing process model. The challenge has increased the need for software wherein the amount of transferred CAD data will increase.

The aim is to describe the current situation of the process in the company and to find out most essential information flow between work phases. In addition, the aim is to find development ideas from the point of view of data exchange, and how the new machine can be implemented into the current operating model of the programming department. This thesis aims to simplify the current sheet metal process and to find the factors that have an increasing effect on the efficiency.

The research is limited to the case of the sheet metal process from design to production and focused around the programming department. Attention has been paid to the programming process and to the production steps such as punching and laser cutting, shearing and bending that partially interact with NC programming. Thesis' research area is shown in Figure 1.

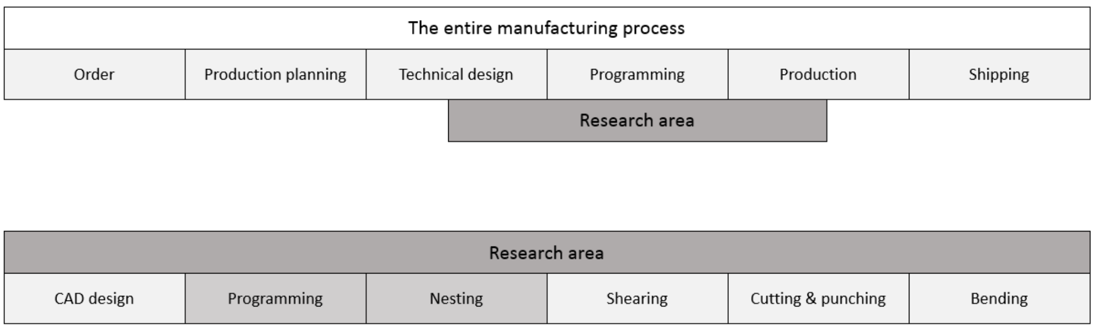

Figure 1. *Research area of the thesis*

Programming is positioned between the design department and the production, from which it is in direct interaction with each direction. In the target company, programming and nesting are both integrated into the programming department. In addition, the design department is connected with production planning that operates under logistics department. This department gives guidance on initiating the production and thereby on starting the programming.

1.3 Thesis structure

The content of this research is divided into two parts, theoretical and empirical. The first part of this thesis is theoretical and based on a literature review. The theoretical part presents a sheet metal manufacturing process from design to production. It aims to find out what affects the sheet metal processes from the NC programming point of view. Additionally, it aims to find the factors that are relevant to the research of this thesis and determine an informative meaning of these procedures.

The second part of the thesis is empirical, and it includes the collection and analysis of the data. This data acquisition phase is carried out in two steps, the first step includes an instructed factory tour and the second includes the semi-structured interviews. Based on these observations, the collected data is analysed from the perspective of the study. The research methodology is presented in Chapter 2.1.

Based on this information, the company's sheet metal process is mapped out, and the key elements of the process are presented in the process flow charts with related information flows. Further on, based on the process flow charts, the potential problem areas of the process are studied to find potential development suggestions.

The first phase is to review the results of the literature study. Subsequently, the current state of the company is presented on the basis of the mapping. In the third phase, the challenges identified in the process are presented, and the aim is to provide potential ideas for further development of the process.

2. LITERATURE REVIEW

The objective of this study is to describe the current sheet metal process and find the related information flows. This theoretical part proceeds logically forward and aims to describe each work phase as accurately as possible. These work phases are described at a level that allows to form a general view of the sheet metal process based on the collected data. Attention has been drawn to information flow between work phases and this is presented in each section. In addition, the operational actions related to the work phases are presented.

This theoretical part aims to reach sufficient understanding of the sheet metal processes that are used in the target company. The used research methodology and materials are presented in Chapter 2.1. After this, Chapters 2.2−2.7 discusses the following topics: design, programming, flat processing, bending, assembly, and cost structure of the sheet metal parts. In these fields, the relevant theory and the empirical part of the study form a basis for the thesis that aims to provide an answer to the research question and objectives.

2.1 Reserch methodology and materials

Methods used in the study are selected to complement each other. The methods aim to take into account the starting points and the study objectives. The methods of this thesis are presented in the following sections.

2.1.1 Literature review

The basis of this study is formed with a literature review with the aim to create a sufficiently broad overview of sheet metal processes. All the work stages are presented from the perspective of the overall process, proceeding forward logically. The topics include essential information and the factors affecting the sheet metal process. In addition, the information flow between work phases and the empirical knowledge that affects the process are presented under each topic. In addition, efforts have been made to find the impact of the operational activities.

Literature review was initiated by a preliminary study of literature. The purpose was to provide a sufficient overview of the research topic, creating reasonable limits for this thesis. This allowed the collection of source material wherein the note-taking was also possible. Based on this information, it was easy to expand knowledge when the research aim was specified.

This study was carried out by studying printed literature and electronic publications. The source material consists of books, scientific and conference publications, and the thesis.

The material was collected by using library search services provided by the Tampere University of Technology and Aalto University.

2.1.2 Case studies

The empirical part of the study is carried out as a qualitative case study. This attempts to achieve sufficient and comprehensive understanding of the research subject. According to Hirsjärvi et al. (2013, p.181, 182), the objective of qualitative research is to understand the object of study. In this method, the researcher determines the target group and conducts a sufficient number of interviews in order to obtain the desired information. The entire of the collected material depends on the amount of the interviewees. In this thesis, the qualitative interview study consisted of three interviews.

Hirsjärvi et al. (2013, p. 164) explain some typical features of a qualitative study. According to this, a qualitative study is a comprehensive data acquisition process where data is collected in natural and real-life situations. This aims to reveal unexpected aspects that provide perspectives to the case study. In order to achieve this, favouring methods that allow the interviewee's views can be expressed. What is also interesting is that the research plan takes shape as the study progresses. This was noticed in this study because the reserved time for the interview would not be sufficient to address all the issues.

Hirsjärvi et al. (2013, p.182) remind that conclusions drawn from the qualitative method should not be generalized. The idea is to examine one case so closely that the conclusions are visible in what is generally observed. According to this, it can be assumed that a limited number of interviews is sufficient for this study in order to illustrate the process in general.

The interviewed people were selected from the focal areas of research. Two employees worked in the designing department and one in the programming team. The interview questions were formed based on the literature review and the information from the company. The questions were formed so that they allow the widest possible understanding of the sheet metal process. The aim was to find out what kind of information flows and operations are connected to each process phases. Based on this, a view of the current process and bounded operations, information and material flows were formed. Questions used in this study are presented in appendix A.

The method used for data collection was semi-structured interview. Hirsjärvi et al. (2013, p.208, 209) present three interview methods: structured, theme, and open interview. The semi-structured methods used are the combination of these. The interview is based on the form in which the questions are presented in order but are closer to an open interview. Thesis research interviews were allocated according to the interviewee's knowledge but in a predetermined order of the paraphrase.

The interviews were carried out in three days, despite of all the issues I did not have time to deal with. Because of that, the questions are divided according to the assumed know-how. This way it was possible to create an overview. This is complemented by a guided factory tour during which the essential findings of the research have been written down.

2.1.3 Information analysis

Hirsjärvi et al. (2013, p.221, 222) present in their book some methods for the analysis of the material. According to this, the qualitative data would be appropriate to letter, as analysing the material would be easier. There is no unambiguous way to letter but it would be appropriate to know before analysis how the material will be used. Thereafter we proceed into the analysis stage, which will discuss the lettered material.

According to Hirsjärvi et al. (2013, p. 224, 225), the analysis can be structured in approximately two ways, the first aiming to explain by usually including statistical methods and attempts to explain, and the second is a consensus-oriented method that usually uses qualitative analysis to draw interferences. An analysis can be done in many ways and there are no strict rules for carrying it out. A qualitative study generally uses practical structuring methods for analysing, such as a thematic approach, specification, typecasting, etc.

The analysis of the study has been started with lettering where the recordings are written up. At this point the interviewees' body language or essence has not been taken into account at all, only the consulted information is written down. Based on these, the flow charts of each interview regions have been generated. All identified factors in the interview are drawn on the chart with the associated information.

Based on the theory and generated diagrams, an overview of the entire sheet metal process can be formed. This has been linked to the related information flows. This formed view of the whole process, a current state of the company, made it possible to form a closer examination of sub-processes. The lower level processes have been described with the associated information, such processes are e.g. nesting, laser cutting, and bending.

Based on the previous process models and the associated theory, it was possible to assess the current state of the process. That makes it possible to form strategies for the development of the current process. These strategies for developing the company's operations are presented in the context of the case study.

2.2 Design

Design is fundamental to the sheet metal process and it has a huge role in manufacturing from cradle to gate. At the same time there are many design aspects that have a direct effect on the final product: how the parts fulfil the designed task, what is the cost of the part, and is the part manufacturable. All these properties depend on design engineers. Buchfink (2006, p.36) states on Fascination of sheet metal, that engineers need to take material properties into account, and they need to have extensive knowledge of sheet metal manufacturing when creating the product.

Groover (2008, p.715-720) divide the general process of design into six phases. These phases are depicted in Figure 2.

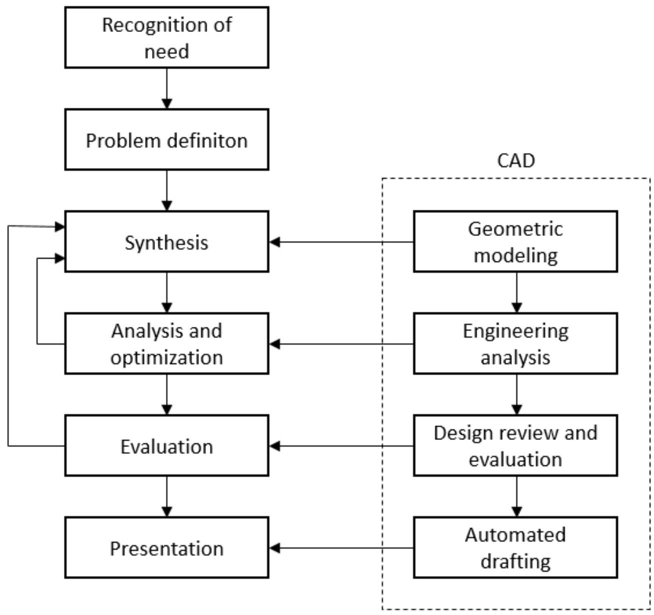

Figure 2. *The design process using computer-aided design. (Groover 2008, p.715, modified)*

The first phase, the recognition of the need usually starts by the design engineer or sales person and is based on some technical issues that could be solved by design. An old design or a new product line may need improvement by design. Regardless of the situation, the task is to find out what really needs to be done. The second problem definition is a phase where all the key properties for the product are collected to a specification. These properties are physical characteristics, function, costs, quality and operating performance that provide the framework for the design process. (Groover 2008, p.716.)

Phases, synthesis (3) and analysis (4), and optimization go closely together. The products are composed of several parts or subsystems that are fitted together. This requires an interactive connection between these phases in order to form an optimized product. Each part need to be improved, redesigned, analysed again, etc., which finally generates a new product influenced by synthesis, analysis, and optimization. (Groover 2008, p. 716.)

The fifth phase, evaluation, measures how the new product fulfils the requirements that were set during the problem definition phase. When the product or a prototype model has been fabricated, it is possible to evaluate operating performance, quality, reliability, and other criteria. In some cases, the evaluation can be done before fabricating by using design software, which allows e.g. simulation and tools for the evaluation. The last presentation phase includes documentation, which requires a design database where drawings, material specifications, assembly lists, etc. can be stored. (Groover 2008, p.716.)

Today, there are a variety of design software to support design engineers' work. In the target company, Computer-Aided Design (CAD) programs are generally used, presented later in this thesis. From the thesis point of view, it is meaningful to look into information knowledge: how designers take into account the needs of manufacturing and how information is shared with the production and programming department.

2.3 Programming

Programming plays an important role in this study. The target company has two combi cutting machines with punching and laser cutting features. The company has invested in a new laser cutting machine that has been delivered in the spring of 2017. These numerical controlled machines are dependent on programming. In the company, this is carried out with a numerical control (NC) programming software, operated by three programmers. Over the 85 per cent of all sheet metal parts pass through this stage. The stage forms a part of the process chain where all the knowledge of a man and a machine is combined to produce the part (Buchflink 2006, p.51).

Buchflink (2006, p.51) explain that the programmer's task is to act as a link between design and production. Their job is to collect the design information into a one program, so that the product can be produced smoothly and efficiently. Automation has increased the design requirements, so the programmer must be even more accurate in making sure that the designed product can be manufactured by available machines. If design errors are detected, programmers need to correct these before programming and releasing the product for production. From the perspective of the thesis, this means that attention must be paid to the programmers' empirical knowledge. Other point of view is how the information is received from the designing department and shared into production use. (Groover 2008, p.187.)

Nowadays, NC programming is not only for laser cutting or punching but it can also be used with bending and other methods. Buchflink (2006, p.149) indicates that, today, bending forms a bottleneck in production because of productive punching and laser cutting machines. Buchflink explains that one laser machine can fully employ two press brake machines that could be made to operate more efficiently. Solution for this could be found in experienced operators and good programming software, which would increase the efficiency and reduce downtime. Therefore, it is important to find out what is the company's degree of readiness for the programming of bending.

Programming can be performed in many ways, locally at a workstation or remotely at an office. According to Groover (2008, p.187), regardless of the destination, programming is implemented using a variety of methods ranging from manual to highly automated. These methods are divided into four groups: manual part programming, computer-assisted part programming, part programming using CAD/CAM, and manual data input. This section presents these methods and basics for NC-based systems.

2.3.1 Numerical control systems

Groover (2008, p.156) explains that numerical control creates a way of programmable automation in which mechanical operated machine tool or other equipment are controlled by a program that uses alphanumeric data. In practice, this data includes relative position information between a workhead and a workpart. The workhead is a used machine equipment as cutting or other processing tool, and the workpart is the object under processing. These programs are programmed as well as needed from the manufacturing point of view. According to Buchflink (2006, p.52), in laser cutting and punching cases, the programs contain the following information: The coordinates are included for all movable elements giving a path, how these are driven. For example, a coordinate guides how a sheet is moved in a punching machine or laser head on a laser cutting machine. In addition, information on the function of the machine is used.

NC technology

Groover (2008) extensively discusses NC technology in his book, and presents basics for the NC systems. He explains that NC systems are divided into three basic components: a part program of instructions, a machine control unit, and processing equipment. Three main components are shown in Figure 3.

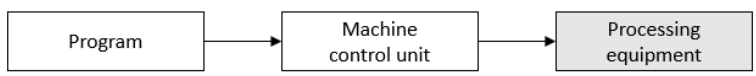

Figure 3. *Basic components and flow of NC system*

According to Groover (2008, p.158), the first of the basic components is a part program that includes detailed step-by-step knowledge of how the processing equipment is controlled. The workpiece's and process equipment's relative behaviour is included as shown earlier. In addition, the feed rate is usually included in cutting tool selection, and other functions according to the procedure. A finished program is then transferred into the machine control unit. Conventionally, the transfer has been operated by punched tape, magnetic tape, floppy diskettes, and RS-232 or manual data input. Today, program files are sent to the machine using the company's IT network (Buchfink 2006, p.63). In practice, these files are stored in the database from which they can be picked to the machines.

The second component is a machine control unit (MCU), a microcomputer with related control hardware. In addition, a control system software, calculation algorithms, and a translation software are included. The main task is to convert a program of instructions into a form that is compatible with the machine's control software. The translation software in use is called a postprocessor, in which the program typically formats the output for a device (Butterfield 2016). Today, all new machine control units are based on computer technology and not on a hard-wired controller, and for that reason the computer numerical control (CNC) term has taken place. The NC and CNC terminology are currently being used side by side and can be used as synonyms. (Buchfink 2006, p.51; Groover 2008, p.159.)

The last component is the processing equipment, the part of the machine that performs the process. Groover (2008, p.159) provides an example of this, machining where the workpiece is machined into a completed part from nothing. The process is carried out step-by-step and the instructions of the program are performed by the machine control unit. In machining, the processing equipment include the worktable and spindle that is rotated by the motor, and all these are driven by the processing equipment. In the case of the target company, the machining has not been used but the same can be applied to the laser machines. There the processing equipment consists, for example, of a laser head and the worktable.

CNC systems

As previously mentioned, conventional NC systems are separated from modern CNC systems by the MCU's hardware. According to Groover (2008, p.164–167), newer CNC system controllers include a high-speed processor, large memories, solid state flash memories, improved servos, and bus architectures. This enables the many advantages compared with previous NC systems. A few important aspects from the thesis point of view are the following: Advanced storage technology offers the ability to store multiple programs in the CNC controllers. This may be useful if the standardized programs were locally available to the operators. Second, the ability to customize the program by the operators. The programs can be corrected and repaired on a machine site wherein it is not necessary to return the program to programming for corrections. Instead, the operator can optimize the program and storage it in a database for further use. The biggest aspect in terms of the thesis is the data transfer interface. The machines are connected to the company's communication network, which allows data exporting and importing. The necessary program can be downloaded from the database. The database also allows to edit the programs locally and remotely when needed. The machine can also share operation information such as workpiece counts, cycle times, and machine utilization.

2.3.2 Manual part programming

Manual part programming is the most laborious a way to generate a program code. According to Buchflink (2006, p.54) and Groover (2008, p.187, 188), programmers need to feed every instruction to the programs line by line. The program is produced by using alphanumeric data based on binary numbers, which is low-level machine coding and can be read by the machine control unit. This method requires much from the programmers, as they need to have knowledge of the functions and the technology. The basic steps of manual programming and related knowledge are presented in Figure 4.

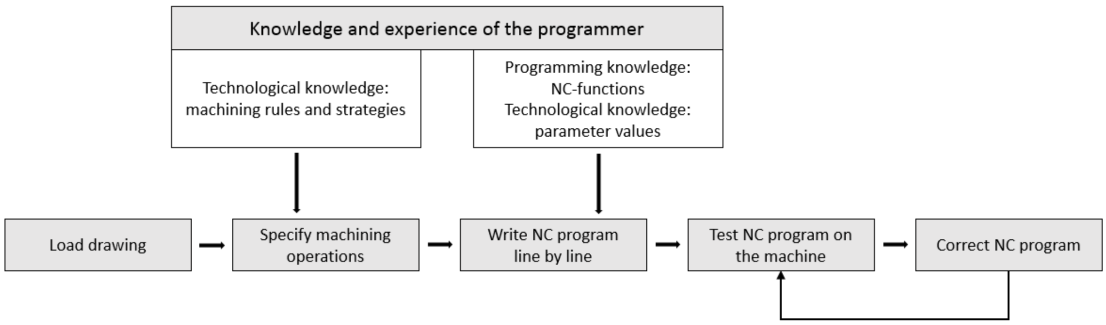

Figure 4. *Manual programming tasks (Buchfink 2006, p.52, modified)*

Initially, according to the drawing, the programmer needs to find right manufacturing methods and ways to produce the part based on the programmer's knowledge and experience. After that the programming phase starts, in which the instructions of the program are written line by line. The programmer takes into account what functions are needed and what are the right parameters for the final product. In addition, there is a variety of instructions and each of them contains information about the move, the speed and feed of the cutting operation, and other information needed to carry out just one work task. A complete NC instruction is called a block. Finally, the programmer has completed the program that will be tested on the NC machine. If the program needs correction, it is tested again after each correction. (Buchflink 2006, p. 52; Groover 2008, p.188.)

Groover (2008, p.189) states that manual part programming is a very useful method for point-to-point or contouring jobs in straightforward cases. As an example of this, he presents drilling as a point-to-point method and explains that milling and turning are simply handled when only two axes are involved. In complex three-dimensional cases, it is advisable to use computer-assisted part programming.

2.3.3 Computer-assisted part programming

Manually program specifying can be time-consuming when all instructions are defined line by line, which increases the possibility for errors. Consequently, the workload can be reduced by using the programming software. The software includes all the information needed on NC functions, technology data, and processing rules. Programmers need only to choose the right process parameters and strategies to optimize the process. Then the software is able to define machine operations automatically and to generate a compatible program for the machine. In this high-level programming, the program is written in English-like statements and finally converted into a low-level machine language. (Buchflink 2006, p. 54; Groover 2008, p.189.) Figure 5 illustrates Computer-assisted Programming steps.

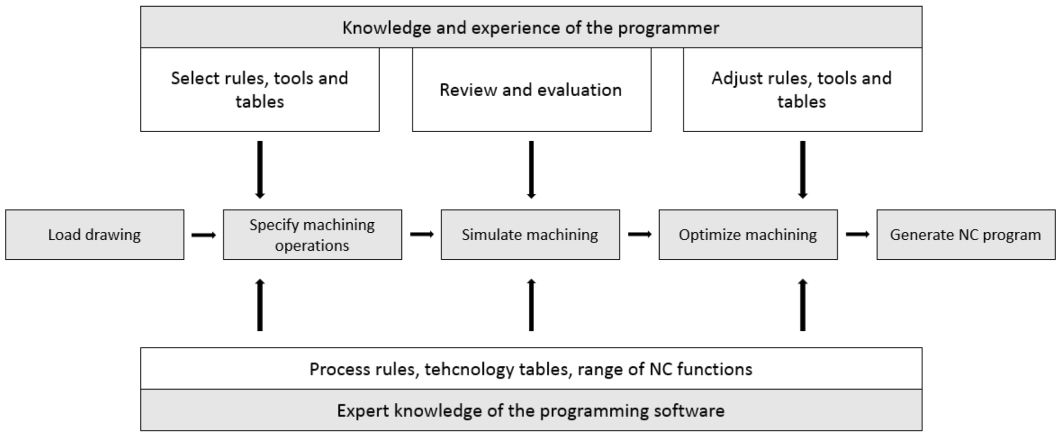

Figure 5. *Automated programming tasks on Computer-assisted Programming (Buchfink 2006, p.54, modified)*

As Figure 5 shows, the available information can be distributed across two parts, knowledge and experience of the programmer, and expert knowledge of the programming software. When required information on the performance of the machines is tied to the software, errors caused by human activity can be reduced. In addition, this releases resources for the optimization of the program, which can be supported by computer simulation. Finally, the finished program can be generated and released to the machines.

Groover (2008, p.189–192) provides a slightly different view to the computer-assisted part programming. He has divided this process into two parts, depending on the author. Figure 6 shows how different tasks are divided between the programmer and the computer.

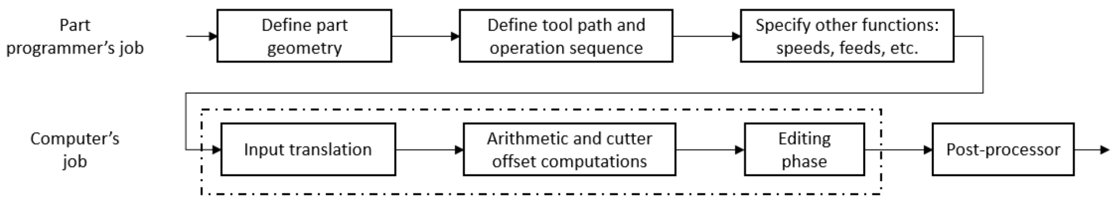

Figure 6. *Computer-assisted part programming (Groover 2008, p.191, modified)*

Programmers have two main tasks that are geometry assay, and defining a tool path and operation sequence. Firstly, the programmer identifies all elements of the part and provides dimensions and locations for these in relation to other elements. The second phase is to define the tool path for the machine equipment e.g. laser head, spindle, etc. In this stage, the programmers have to add also other information such as the name of the program, identify each machine tools and when these are used, specify cutting speed and feed rates, choose cutter size and adjust tolerances in circular interpolation. Then the computer takes the other factors into account. (Groover 2008, p.191.)

The tasks of the computer are divided into four parts from which three are carried out by using a high-level programming language. The first phase, input translation, is a module that converts instructions to computer-compatible form. The second, arithmetic and cutter offset computations include mathematical computations that are needed in defining a part surface and a tool path. This phase gives out a file that mainly consists of the tool path data. In the third, editing phase, the computer generates a new file that provides readable data on cutter locations and machine tool operating commands. Now this file is ready for postprocessing where the file is converted into a low-level language, a form which is compatible with the NC controller. If more than one machine is being used, the postprocessor files need to be written separately for each machine, except for the same manufacturer's identical machines. (Groover 2008, p.192.)

2.3.4 Part programming using CAD/CAM

Modern design programs enable versatile programming machines such as the laser and punching, which has replaced the traditional programming methods. Kujanpää et al. (2005, p.128) explain that line programming is almost outdated and now mainly used to repairing programs and compensating dimensions. These actions can be implemented on the operator interface for the machine controller. Instead, today's programming is carried out with CAM programs, where CAD drawing is generated to the NC program for machining. Typically, CAM software also has a nesting feature that nest parts to the sheets with optimizing the utilization, which can be used with laser machines. Groover (2008, p.192) adds that the software makes up the computer interactive graphics system where both functions, design and manufacturing, are integrated.

Today, there is a large amount of successful CAM software for 2D laser machining. The possibilities for the systems vary depending on the software provider. Some software only allows creating the programs, whereas some can handle stock accounts and materials management. The typical laser cutting CAD/CAM programming process is presented in Figure 7. (Kujanpää et al. 2005, p.128.)

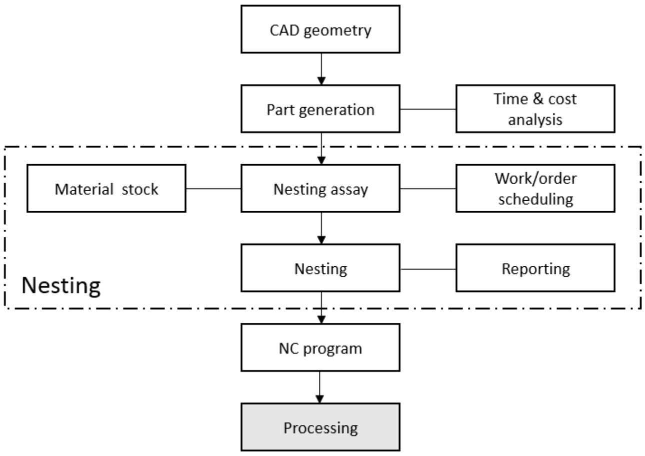

Figure 7. *CAD/CAM programming (Kujanpää et al. 2005, p.128, modified)*

The first phase in the CAD/CAM programming process is importing, in which the designed part model is picked up from the CAD/CAM database. In two-dimensional cases, the most important file formats are .dxf, .dwg, .ige, and .mi (Buchflink 2006, p.58). When CAD/CAM systems are used, defining the part geometry is no longer necessary because all geometrical data, such as dimensional, is already included in the model. In this way, one time-consuming phase, geometry definition, can be removed, even though programmers still need to label these defined geometric elements. These work phases can also be avoided by using an automatic labelling feature of the software. (Groover 2008, p. 192, 193; Kujanpää et al. 2005, p.128.)

The next phase is part generation, in which a tool path is defined by computer-assisted part programming. Another way is to use a module of the CAD/CAM system that automatically generates the tool path with predefined parameters. However, before that the programmer chooses the right tool for cutting. The CAD/CAM software often includes a library for the tools, and the programmer can identify the appropriate tool. Finally, the finished part program can be simulated by the CAD/CAM software by improving information about processing time and material usage. This information can be shared for the analysis of time and cost. In addition, Buchflink (2006, p. 59) mentions that software allows the possibility of optimizing manufacturing techniques and machining processes without prototypes and test runs. (Groover 2008, p. 192, 193; Kujanpää et al. 2005, p.128.)

Kujanpää et al. (2005, p.128) present that the next phases are nesting assay and nesting itself. Nesting is an operation that needs to be done to all flat processing parts before the cutting operation. This operation is left out in this context and described later in its own subsection 2.3.6. After this, the ready NC program is converted into a low-level language by postprocessing, as presented in the previous chapter of computer-assisted part programming. Then this part is ready for manufacturing.

Groover (2008, p.193, 194) states that the fully automated part programming procedure can be possible in the future. It requires that part geometry is completely defined by designers in the designing phase, also sufficient logic and technical knowledge has to be available. Initially, it would be possible to implement this using well-defined parts with simple geometry.

Buchflink (2006, p.58, 59) presents an interesting perspective concerning the available software. Systems that are offered by the machine manufacturers include already optimized and tested technical data of their machines, in which case the use of machines is more efficient. On the other hand, he mentions that the systems of the software developer can create programs for different machines, whereas machine manufacturers' software is suitable only for their own machines.

2.3.5 Manual data input

According to Groover (2008, p.195, 196), manual data input is a method for modern CNC technology with minimal investments, in which machine operators define and insert geometrical data and motion commands directly into the machine control unit. This can be done by using the machine's display and an alphanumeric keyboard. The biggest risk of this method are human based errors that appear in connection to complex procedures. The errors can be avoided by the user-friendly interface with which the operator is instructed to use the essential parameters from the machining point of view. Then the input can be given in a logical and consistent way. In modern manual data input systems, machine operations are visualized for operators and verified in this way. For example, a tool path can be animated and displayed for operators. Such system only requires that the operator has knowledge of both the technical drawings and the machining process.

2.3.6 Nesting

As already mentioned in the CAD/CAM programming section, nesting is the next phase after part programming and before flat processing. It aims to place the cutting parts in a sheet so that the costs are minimized, which requires the maximum utilization of the raw material (Lee et al. 2008). Niemi (2003) presents in his journal article that positioning the parts on the sheet as effectively as possible forms a challenge that is called the nesting problem. According to Buchflink (2006, p.61), in nesting, every programmed part is placed on the sheet by using a nesting software. Programmers define the necessary parameters and the quantity of each part. Then the used nesting program takes into account the manufacturing specifications and the distance between the nested parts. Finally, the program generates a nest where sheet utilization depends on the used nesting strategy. By selecting the right method, it is possible to decrease the consumption of material and to optimize machining.

In his thesis, Sun (2002) widely discusses nesting problems for customer-oriented sheet metal manufacturing. In his thesis, nesting is divided into two parts, rectangular and irregular nesting. He explains that rectangular nesting is used with shearing machines where cutting is based on rectangular shapes. In addition, irregular nesting is most used with laser cutting machines and other router-type machines. Buchflink (2006, p.61) mentions that these methods or their combinations are the solutions for efficient nesting. The target company performs rectangular sheet cutting process locally and manually on shearing machines without nesting. These rectangular parts are cut according to a cutting list and produced based on the dimensions of the sheet. Instead, irregular part cutting plays a bigger role in their manufacturing and it is presented on this section.

In the target company, nesting is performed from the point of view of the laser cutting, where punching machines are integrated and called combi machines. Sun (2002) proposes that in this kind of use, irregular nesting becomes necessary. Many algorithms have been developed for this purpose that enable efficient computer-based nesting. The basis for nesting is a material stock, generally rectangular metal sheets that are to be filled with flat parts. The challenge is part arrangement in which irregular parts can’t overlap the sheet. That is because there are some factors, such as machine configurations or grinding direction, that affect the part’s orientation. Because of this, the parts can be rotated 0/90/180/270 or 0/180 degrees. From the company’s point of view, the orientation of the parts is important because the grinding direction of the sheet metal parts affects its appearance. How it can be controlled from design to the nesting phase, is the real challenge for the company.

As already mentioned, the nesting is carried out with nesting software. However, not all things can be taken into account in computer-based nesting. Sun (2002) presents three main things that should be considered in the nesting process. These are manufacturing costs, delivery time, and inventory. Figure 8 present the computer-based nesting process with attached information.

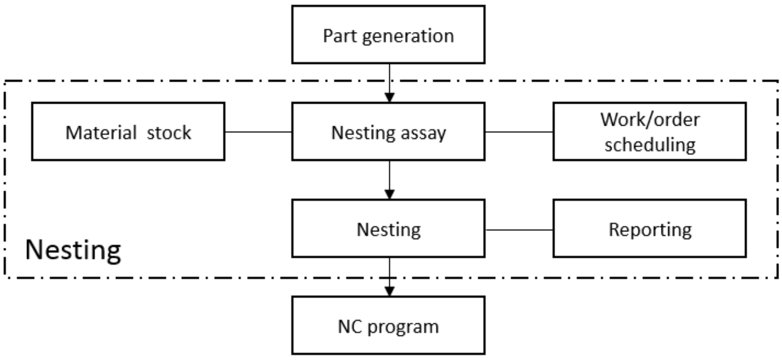

Figure 8. *Computer-based nesting process*

The nesting process included two basic steps, nesting assay and the nesting itself. In the first phase, the programmer takes into account all things that affect the process, such as available material stock and production schedule. According to the production plan, programmers start the nesting planning so that the parts are delivered on time. At the beginning, the programmers load the already generated programs to the nesting software and add the required quantity of the parts. The programmers should take into account the production orders and try to make a nest according to this. This method is available for keeping the inventory at the minimum level. In the second phase, the nesting software automatically arranges the required parts in a sheet and optimizes the sheet utilization for reducing the manufacturing cost. After that, the programmers can manually modify the arrangement if needed. When the nesting is ready, the program provides information such as utilization and material need, which is usually shared for further calculations. (Buchflink 2006, p.61, 62; Sun 2002.)

The programmer also prepares the setup plan for production, including information on what the machine operator needs. The general information also includes, for example, the machine type, current date, programmer name, operator name, material, and the sheet size. The second part of this is the production introduction that includes settings of what the operators need to manually add to the machines, and how the tools are used. Today, this can be done automatically with the NC software. These instructions are printed or shown on the display of the machine. The first one is the best from the information point of view, because the print can be followed throughout the entire production process. (Buchflink 2006, p.55.)

2.4 Flat processing

Flat processing forms the fundament for all sheet metal parts. In other words, every manufactured sheet metal part is formed from a blank (flat pattern of the part) into a finished part. These blanks need to be cut from a sheet, and the material depends on the desired final product. The blanks are produced from the sheet metal using the following methods:

laser cutting, punching and forming, and shearing. These methods are used extensively in the company and described in this section.

2.4.1 Laser cutting

Laser cutting is a separation method in which sheet metal parts are separated from the sheets for production. This separation is usually done in a thermic manner by laser cutting. Traditionally, laser cutting is done with 2D lasers, but nowadays 3D machines have become common in the industry. Nevertheless, the most widely used flat cutting machines are usually 2D machines with flying optics. (Kujanpää et al. 2005, p.92; Klocke 2014, p.407.) In the target company, laser cutting is carried out with three 2D lasers, of which two are combi lasers and soon there will also be a 2D laser with material handling. This new machine includes options for loading and unloading, and parts separation for finished parts. Due to this, 3D lasers have not been discussed in this section.

Laser cutting machines are typically divided into three groups according to the movement of both the material and the laser head. These three types are: moving material, flying optics, and a combination of these. The traditional flat cutting machine is the simplest type of a laser workstation, in which the laser beam is mirrored to the cutting optics and focused onto a fixed point. At the same time, fresh air or nitrogen is blown into the laser beam channel. The high-density energy of the light beam is focused on the workpiece to remove material by vaporization and ablation. This light is pulsed into the cutting spot where the generated energy impulse produces a combination of evaporation and melting. The distance between the workpiece and the cutting spot is controlled by a sensor, placed in the laser head. (Buchfink 2006, p.90–99; Groover 2007, p.632; Kujanpää et al. 2005, p.95.)

On the workstation of the moving material cases, the workpiece moves in relation to the stationary cutting head. This allows that the workpiece is clamped into the moving bed. In addition, lower support for the workpiece is needed, which is usually carried out with bearings and/or brushes. This cutting method requires that the cutting parts are held in place by micro-joints or micro-weld within the sheet skeleton. Separation of the sheet skeleton and the parts requires an extra work phase. These may also be unused, and the cut parts are dropped from the cutting surface into the collection box by using so-called hatches. Kujanpää et al. (2005, p.95) states that in the industry, the most commonly used workstation with moving material is a combi machine that includes two options: punching and laser cutting. With this machine, shapes are cut simply by punching, and larger and more complex shapes with the laser. This machine type is also used in the target company. (Buchfink 2006, p.95-99; Kujanpää et al. 2005, p.95.)

The second machine type is the flying optics, in which the workpiece is held in place and the laser moves in relation to the workhead. In this case, the half structure of the machine allows that an exchange table can be loaded automatically, and waste material and parts can be removed at the same time as the machine is running. In this method, micro-joints are not needed, which allows more fluent parts separation and transition to the next work phase. The advantage of the flying optics machine is the smaller size of the workstation and better dynamics of the cutting head. (Buchfink 2006, p.95-99; Kujanpää et al. 2005, p.96.)

The laser cutting process plays an important role in production where it is controlled by operators. In this thesis, the knowledge and experience of the operators has to be taken into account. The focus of this thesis is placed on the operators because they are the end users for the programs made by the programmers. According to Kujanpää et al. (2005, p.126-127), using the laser cutting machines is not possible without skilled operators. They need to have knowledge of how to use these machines, as programming is usually carried out respectively as numerical machine programming, based on NC or PC. The real skills are needed in offline programming and nesting, which are done by the programmers.

In the target company, a new laser cutting machine will be included into the existing production. This means that there is a lot of information to be learned and shared with each other. This information sharing is a big challenge to handle. Kujanpää et al. (2005, p.126, 127) present what needs to be taken into account in the training procedure:

- basic knowledge of the laser
- safety aspects
- laser using
- whole system using
- laser beam adjusting and alignment
- process parameters adjusting and how these affect the process, and
- maintenance and service, including optics.

Kujanpää et al. (2005, p.127) add that training should be continuous during which the simple functions and their use are first learned. The skill level can then be increased step by step. Finally, all operators need to internalize all subsequent changes to the machine, not only the key users. In that way it is possible to take full advantage of the machine right from the beginning.

2.4.2 Punching and forming

Punching is one of the most characteristic and cheapest ways of making a hole. This method is suitable for holes with a diameter up to 100 mm, but also for forming. The modern versatile machines can produce some formed sections, threads, and bends, all this with a single machine. The material thickness is limited up to 12 mm with traditional materials such as mild steel, stainless steel, aluminium, etc. (Buchfink 2006, p.136; Kief 2013.)

The punching process is a shearing operation in which the machine presses a punch through a sheet. There are two parts, upper punch tool and lower support matrix or die, and the sheet is placed between them. The punch travels into the matrix and pushes out a piece that is called a “slug”. The machine may have several different tools that are placed in a tool magazine, also known as a turret. There is a limited number of tools and these tools need to be optimized from the production point of view. The question is, which tools are really needed with each order, and how to avoid the downtime and setup time of the machines. (Buchfink 2006, p.104-140; Kief 2013.)

Punching machines can be used with forming tools, which increases the machine’s versatility. Buchfink (2006, p.107-110) demonstrates how the punch press can be used to creating useful shapes, for example, louvers where cuts and forms are made with the same tool. This is a very useful shape for ventilations that have been widely used in the target company. Other useful shapes and methods are also available, e.g. countersink extrusions, threads, tapping, and roller technology.

The punching machine can be a stand-alone workstation or it can be integrated into the laser machine. The latter of these machines is known as a combination laser machine in which small and simple shapes are usually cut in the punching operation and complex shapes inside and outside contours by the laser. This requires that small cuts can be punched with the tools available. These machines are controlled by NC, which means that programmers must be aware of the features of these machines. From the designers’ point of view, the designers need to have knowledge of how these features can be utilized in the products. (Moreno 2016; Kief 2013.)

2.4.3 Shearing

Shearing is a cutting process and quite similar to punching. In punching, a closed contour is cut out of the sheet, and in shearing, cutting is made by using an open contour. This cutting method is the most commonly used rectilinear cut (Matilainen et al. 2011, p. 170). Generally, this cutting operation is done with a shearing machine used also in the target company and known as a guillotine cutter. (Altan & Tekkaya 2012, p.14.)

In cutting, the sheet is set between an upper and lower blade, and the sheet is attached to the cutting table during the process. The upper shear is typically tilted between 0.5 to 2.5 degrees. With stainless steel, the clearance is generally about 10 per cent of the sheet thickness, but with austenitic and ferritic stainless steels, it is recommended to use a 10–15 per cent clearance. In cutting process, the lower blade stays stationary and the upper blade runs vertically through the sheet. The cutting results depend on blade clearance that indicates the distance between the upper and the lower blade. This clearance varies according to the material, which needs to be taken into account. In shearing machines, this is carried out by numerical control. The operator sets up needed primary parameters of the material and thickness to the machine interface, and it calculates the correct cutting force and clearance automatically. (Altan & Tekkaya 2012, p.14–15; Matilainen et al. 2011, p.170–177.)

From the operational point of view, the sheet positioning plays an important role in the quality of the end product. When the sheet is placed between the blades with backgauges, there are always some cutting errors to the process that multiply every time the same sheet is arranged into the backgauge. That is because when cutting is repeated, the designed cutting line moves a bit forward. The sheet can be repositioned by using guide lights or front gauges when the error is not multiplied. It means that the operator needs to have knowledge of how the used methods affect the end product. In addition, the experience-based knowledge plays a role in this stage. (Matilainen et al. 2011, p.175, 176.)

2.5 Bending

Bending is the most commonly used forming method in sheet metal production. Bending is a versatile operation in which a bend is usually done along a straight line. This process phase allows various sheet metal shapes as L, U, V and Z by using different bending tools and methods. (Kunmar et al. 2016, s.245; Matilainen et al. 2011, p.239.) These bending methods are: die bending, wiping, folding or flanging in special machines, or sliding the sheet over a radius in a die (Gwangwava 2014, p.6020). In the target company, die bending by press brakes is commonly used. The press brake method is presented in this chapter.

2.5.1 Geometric tolerances

The challenge in the bending process is how to preserve geometric tolerances from designing to the final part (Kim et al. 2007). From the point of view of this thesis, it is important to find out how the crucial data of geometric tolerances travels from designing to production. Matilainen et al. (2011, p.248) present that it is important to notice the following factors already in the design phase. These are: the bending radius, the height of the bend flanges, and the bend allowance, that have a direct effect on the final geometry. It is interesting to find out how designing knowledge corresponds to the operators' experience-based techniques. For example, how designed dimensions of the finished part are noticed by the operators, and what is the bending order. Matilainen et al. (2011, p.256) also explain that there are always some dimensional errors somewhere in the parts that are placed by the bending order. This means that the designers should notice these sections where inaccuracy may be allowed and extend these to the drawings. That is because the operator most likely does not know which junction points and dimensions are important in the assembly. Finally, dimension accuracy depends on how precisely the bend allowance is defined, and what is the accuracy of the manufacturing methods and thickness tolerance of the sheets.

Matilainen et al. (2011, p.253, 254) handle in their book bending accuracy and the factors influencing it. According to it, bending usually reach 0.5 mm correctness, which can be required for all available manufacturing machines. Overall accuracy requirements focus on the bending itself and on its position. The determining factors are angle accuracy and edge straightness, machine compliance, and tools' condition and choosing. In manufacturing, these factors are the springback, properties of the material, tools, thickness, and blank width.

In production, bending's position accuracy is defined in relation to the guide edge or the base holes. There are a few things that affect the position accuracy of the bending line. Firstly, the priority basis of control should be on using the guide edges for bending. The second point is using corner cut-outs and last base holes. Other factors are used backgauges and guides, positioning and repeat accuracy, calibration accuracy of the NC gauge, and working tolerance and positioning of the workpiece. (Matilainen et al. 2011, p.254.)

2.5.2 Press brakes

The press brake, shown in Figure 9, is the most commonly used manufacturing machine type for sheet metal part bending in sheet metal industry. Buchfink (2006, p.142) and Matilainen et al. (2011, p.240, 241) state that many sheet metal parts are fabricated by using the following operations: air bending, bottom bending, or folding and hemming. Mäki-Mantila (2001, p.6) and Matilainen et al. (2011, p.240) show that on these machines, the workpiece is set between the punch and die cavity tools, and the punch moves down and presses the workpiece into the die. In the work process, these workpieces are placed in the machine by backgauges.

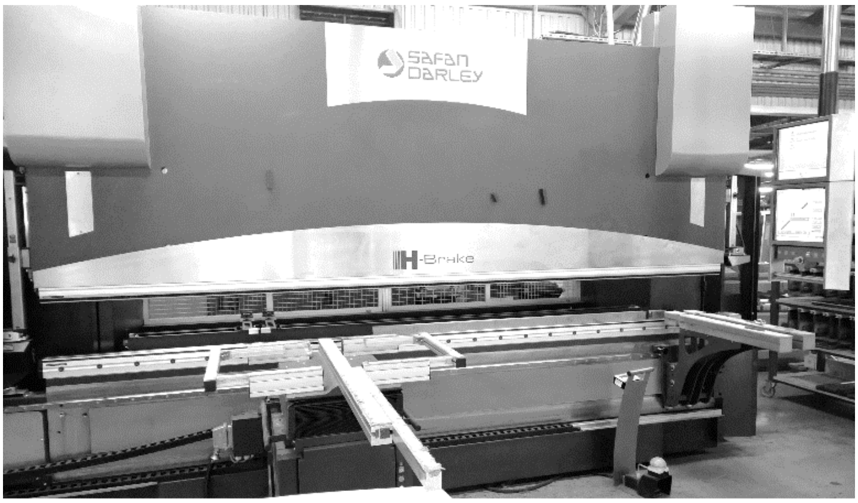

Figure 9. *A Safan Darley's press brake machine, used in the target company*

The backgauge shows how far operators need to push the workpiece. These gauges help in positioning and keeping the workpiece in place. In modern press brakes, the backgauges and press depth are numerically controlled, which allows the repeatability of bending. The benefit with numerical control is that it decreases the setting time. With manually operated backgauges, the setup time is several minutes longer than with numerical controlled, where it is about few seconds. Because of the degreased setup time, the workpiece can be bent under one cycle where the backgauge automatically repositions for every stage. This allows for a smoother work flow and faster part movement into the next work phase. (Mäki-Mantila 2001, p.8.; Matilainen et al. 2011, p. 240.)

The level of automation can be increased, otherwise it creates challenges to the operator-based usage. Ollikainen (2003, p.129) states in his study that the human activity-based errors decrease at a higher automation level even though it may not bring any improvements. The amount of errors can be even higher with automation, as from the quality control point of view, with higher volumes comes a higher production risk level. In operator-based bending, quality is controlled in real-time wherein the errors can be tackled more rapidly.at

Automation also increases design challenges because the machinery must be taken into account already in the design stage. Buchflink (2006, p.61) explains that every bending machine requires a characterized bending table. Depending on the range of the sheet metal processes, over 100 tables may be easily required based on each tool, material, and thickness.

Air bending

In air bending, a sheet metal workpiece is bent at three points. These points are both edges of the die cavity, also known as v-tool or bottom tool, and the punch tool. In practice, the punch presses the workpiece into the lower die without collision between the workpiece and the bottom of the die. In other words, the workpiece is never forced into the bottom of the die, illustrated in Figure 10. The formed angle depends on the punch travels on the press brake, but also the used material and design characteristics play an important role. In this method, the created angle varies from 30 to 179 degrees, where the springback is compensated with machine control and angel measure sensors. The punch movement distance and press load are calculated by the machine control. (Buchfink 2006, p.142, 143; Matilainen et al. 2011, p.241.)

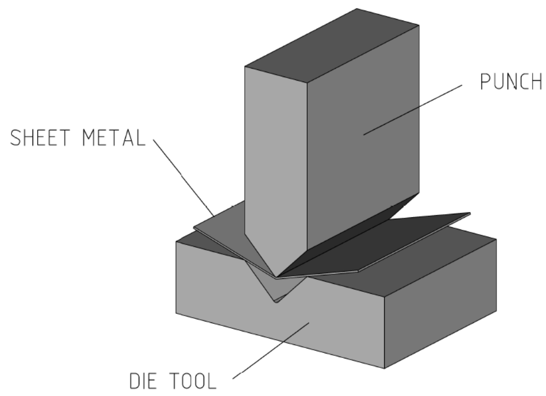

Figure 10. *A principle picture of the air bending*

The air bending method (Buchfink 2006, p.143) is flexible and commonly used because the same bending tool offers several angles without any tool changes. This decreases the setting time of the tools and is cheaper. The machine operator also has a direct effect on the cycle time and on the overall cost of the product, as tools and sheet orientation are changed by the operators (Kontolatis & Vosniakos 2009). In addition, Matilainen (et al. 2011, p.241) state that with this method the simple bending tools allow the process to be more automatic and efficient by using numerical control.

Bottom bending

In bottom bending, a punch is pressed deeper than in the previous method. The punch presses a workpiece completely into the lower die by applying three to eight times more pressure. This action is illustrated in Figure 11.

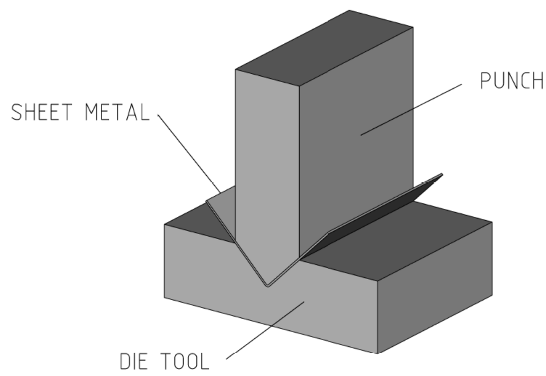

Figure 11. *A principle picture of the bottom bending*

The workpiece is shaped between the tools into a form where the springback disappears almost completely. This method requires that the tools fit together precisely, which increases the need for tools. Therefore, the profits are stabilized at a 90 degrees angle with thin sheet metal parts where the thickness is under 2 mm. In addition, bending can be done in cases where holes, openings, or diagonal edges are close to the bending line. (Buchfink 2006, p.143; Mäki-Mantila 2001, p.7.)

Folding and hemming

Folding and hemming are two-step bending processes in which the edge of the blank is turned and flattened 180 degrees over on itself. Firstly, the blank is bent sufficiently so that the next phase is possible. Secondly, in hemming, the bent flange is flattened together completely, and in folding, the process is the same, but a gap is left between the flanges. These inflections are used to stiffening the finished parts and to providing edge protection. (Buchfink 2006, p.144; Mäki-Mantila 2001, p.7.)

2.5.3 Springback

The bending generates compression and stretch in the bending zone, causing elastic deformation. As a result, the angle of the part bends back a bit when stress is released after the bending. This occurrence in the bending process is called a springback. Managing and evaluating of this is difficult but needed because of automation and automatic assembly, which makes it more important. (Klocke 2014, p.359; Matilainen et al. 2011, p.246.)

Bending the springback itself is not a problem, but it is complicated to manage and a difficult action from the manufacturing point of view. That is because of material properties such as the yield strength of blanks and thickness where these may vary in different points of the blank. Despite of this, material thickness and yield strength are controlled by standards. Standards allow a relatively large variation, which is why in production that is sought to deal with modern machines. The sensors measure the angle of the springback and it is automatically compensated in the bending process. (Buchfink 2006, p.143; Matilainen et al. 2011, p.247.)

As the springback angle is difficult to evaluate with calculations, is it usually managed with test bends where the bended angle is measured and compared with the target. The workpiece is then bended again in the second bending stage where the springback angle is known. This over-bending is a local operation, where the operator’s experience-based knowledge is important to the quality of the finished product. (Matilainen et al. 2011, p.248; Mäki-Mantila 2001, p.10, 11.)

2.5.4 Bend allowance

During the bending process, the sheet length changes as a result of stretching. How much length varies depends on material thickness, bending angle, bending, radius, tooling, and material properties. This stretched length is called a bend allowance and necessary to solve. (Kurtaran 2008, p.486, 487.) Figure 12 presents basics for the initial length of the flat sheet.

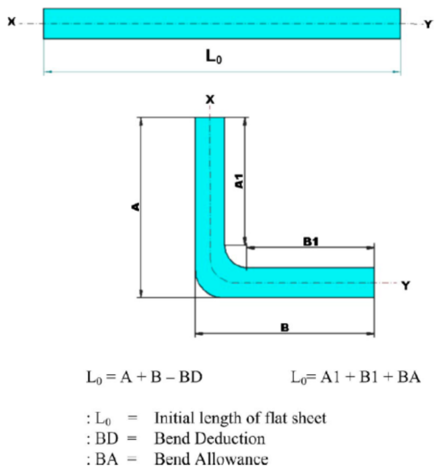

Figure 12. *Bend allowance and bend deduction (Kim 2007)*

The initial length of the flat sheet can be calculated with A1+B1+BA, where A1 and A2 are the length of the legs, and BA is the bend allowance. The bend allowance can be determined with equation 1.

$$BA = (R_p + kt)\theta, \tag{1}$$

Where R_p is inner bending radius, k is empirical constant, t is sheet thickness, and θ is bending angle. The empirical k-factor depends on the material, bending method, and sheet thickness. This k-factor is based on experimental knowledge, which means that this equation does not take the properties of the material into account. (Altan & Tekkaya 2012, p.28–31; Kim 2007.)

Other way to find out the initial length is to use bend deduction, BD. Bend deduction can be calculated with the bending angle by using the DIN 6935 Standard:

$$0° < \theta \leq 90°$$
$$BD = \pi\left(\frac{180°-\theta}{180°}\right)\left(R_p + \frac{t}{2}k\right) - 2(R_p + t), \tag{2}$$

$$90° < \theta \leq 165°$$
$$BD = \pi\left(\frac{180°-\theta}{180°}\right)\left(R_p + \frac{t}{2}k\right) - 2(R_p + t)tan\left(\frac{180°-\theta}{2}\right), \text{ and} \tag{3}$$

$$165° < \theta \leq 180°$$
$$BD = 0. \tag{4}$$

Matilainen et al. (2011, p.252) explain that in these cases, a standard table of the k-factor gives only a good approximate for these values. For exact dimensions, bending tests with each used machines, tools, and materials should be done. However, Kurtaran (2008, p.487) states that bending table generating for general usage is time consuming and costly, although it offers a method for isolating the machine or tooling dependency. After the procedure, the experimental bending data can be included in the CAD/CAM environment. To conserve resources, the CAD/CAM software can use an interpolation method to find corresponding value for the bend allowance. From the thesis point of view, the focus in this area should be on knowledge management: how the designing department has taken into account the available bending tools, machines, and bending tables in their work.

2.6 Assembly

Assembly is a manufacturing operation phase where already produced or other separated parts are connected to form a new entity. According to Groover (2008, p.49), assembly can be divided into two groups, joining processes and mechanical fastening. The first method attaches parts together permanently or semi-permanently with welding brazing, soldering, and adhesive bonding. Out of these three, welding and adhesive bonding are the most used and discussed in this section. The second method for combining parts is mechanical assembly. The parts can be combined by using threaded fasteners such as screws, bolts, nuts, etc. Another way is to use rivets, press fittings, or expansion fits to connect parts permanently.

In this context, electrification of the products can also be mentioned. This goes closely together with the assembly of the components (Groover 2008, p.49). The requirements of the electrical assembly are taken into account already in the designing phase. These are not directly connected to programming, and for this reason they have not been further discussed, even though designers need to have knowledge of how and when electrical connections are done. This affects the penetrations for electrical wires and it needs to be taken into consideration in furniture designing.

2.6.1 Joining processes

In the target company, welding is the most common method in permanently combining parts together. Welding is carried out manually or semi-automatically, depending on the assignment. Manually used welding methods are spot, TIG, and MIG welding. In semi-automatic cases, mechanized welding manipulators are equipped with plasma. These welding methods are shortly discussed in this section.

Plasma welding

Plasma welding, shown in Figure 13, is a joining method where the workpieces are permanently connected by the plasma arc. The plasma arc is generated between a tungsten electrode and the workpiece, where the arc is passed through the nozzle, increasing temperature and energy density. The used plasma gas is formed into plasma in the inner nozzle by ionizing. To protect the welding process, the shield gas is conducted around the plasma arc. Typically, welding is performed by butt welding, but lapped welding is also possible. Tight tolerances can be alleviated by using fillers. This welding method is used mostly with stainless steel. (Buchfink 2006, p.183; Matilainen et al. 2011, p.294–298.)

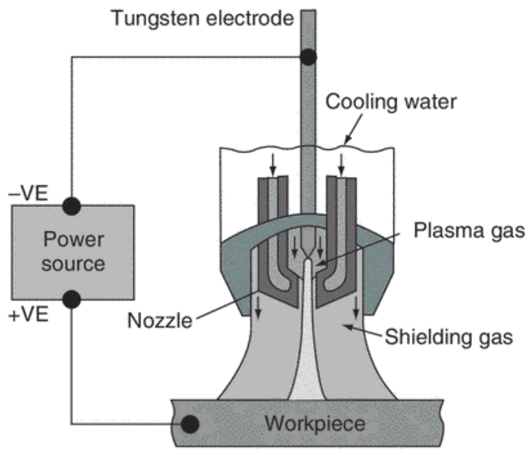

Figure 13. *Principle of the plasma welding process (Mathers 2002, p.148)*

Tungsten inert gas (TIG) welding

TIG welding, shown in Figure 14, is one of the most important thermal sheet metals joining methods. It is a gas arc welding method where an electric arc is generated between a tungsten electrode and the workpiece. In the welding process, the metal workpiece is melted by the electric arc. During the process, the weld and the electrode are protected by a shield gas. The method is suitable for thin sheet metals and it does not require any use of fillers, but it is possible to feed by hand, if needed. (Buchfink 2006, p.183; Matilainen et al. 2011, p.293, 294.)

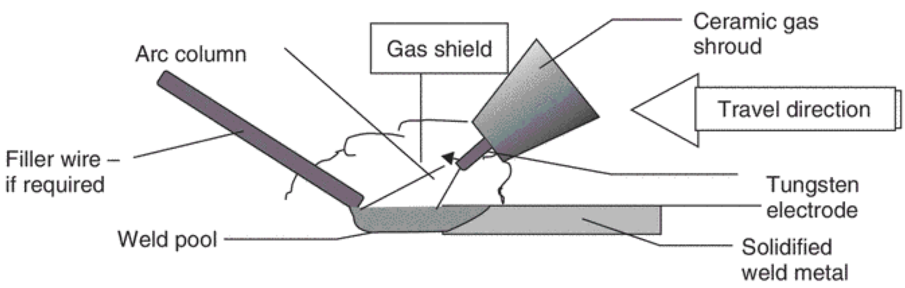

Figure 14. *Principle of the TIG welding process (Mathers, p.98)*

Metal inert gas (MIG) welding

MIG welding, shown in Figure 15, is also a gas arc welding method where an arc and shielding gas are used. The difference to the previously presented methods is that there is no fixed electrode. Instead, the continuously fed metal wire acts as a welding electrode that melts during the welding process. Welding with MIG is generally performed manually and it is suitable for thicker sheet metal plates. There are some issues with heat management with thinner, less than 3 mm sheets. Those are recommended to be welded with a short or pulse arc, a method 2–3 times faster than TIG welding. (Buchfink 2006, p.183; Matilainen et al. 2011, p.292, 293.)

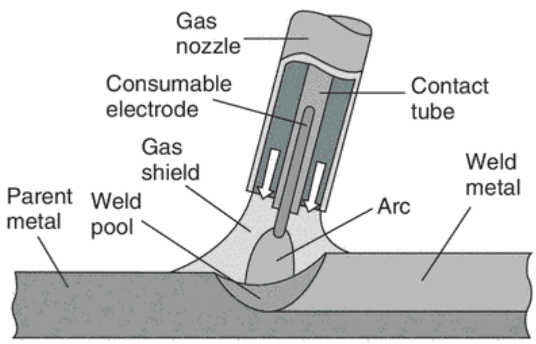

Figure 15. *Principle of the MIG welding process (Mathers 2002, p.117)*

Spot welding

Spot welding, shown in Figure 16, is a resistance welding method where the workpieces are compressed together between the electrodes. The electric current is passed through the workpiece's producing heat that melts the pieces together. Workpieces are pressed together until sufficient temperature is reached. Then it is allowed to cool under pressure, thus ensuring the sufficient strength of the piece. (Buchfink 2006, p.184, 185; Matilainen et al. 2011, p.283, 284.)

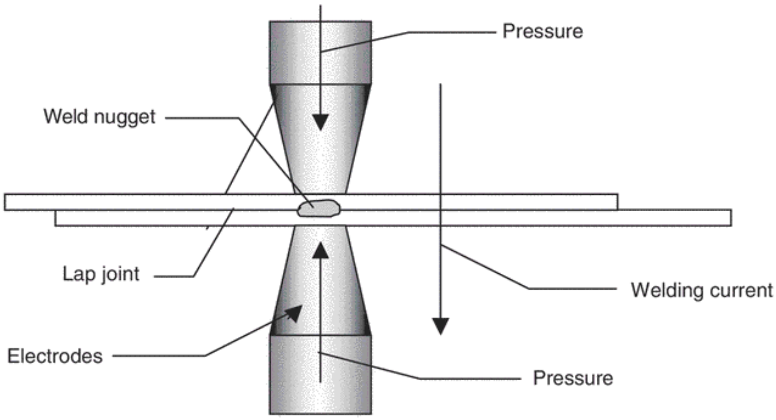

Figure 16. *Principle of the spot welding (Mathers 2002, p.167)*

2.6.2 Mechanical fastening

Matilainen et al. (2011, p.331–348.) and Buchflink (2006, p.174–179.) present widely mechanical fastening methods in their books that take into account all the most commonly used methods. The mechanical joining process can be divided into two groups, non-permanents and permanents methods. Non-permanent methods include threaded fasteners, snap-lock joints, and permanent include rivets, clinching methods, and lock seaming. Mechanical joints hold separate metal parts together by using additional components such as screws and bolts, or by forming, in which clinch joints and lock seams are used. In the target company, the most used threaded fasteners are screws and bolts.

Using threaded fasteners is one of the most familiar joining methods that generates a strong and removable joint between the parts. There are a few methods of making threading to the counterparts: press-in threaded inserts, weld nuts, tapping, blind rivet nuts, and self-tapping screws can be used when threading is no needed. Threading straight to the sheet by using the punch press is the fastest method of preparing the screw connection. In this method, a core hole is cut first and in the second operation, the tool forms the thread. With thin sheets, adequate strength is not always achieved, so welded nuts must be used.

In the target company, the use of mechanical joining methods follows closely the instructions (USPHS 2011) of the U.S. Public Health Service. For example, the used fasteners have to be low profile, non-slotted, non-corroding, and easy-to-clean when placed on food-contact surfaces and in splash zones, where exposed slotted screws, Phillips head screws or pop rivets are prohibited.

2.7 Cost structure of sheet metal parts

According to Ollikainen (2003), Berkhahn and Miyakawa (1993) state that in sheet metal part production, only 7 per cent of the whole manufacturing time is value-adding. This means that 93 per cent is wasted in auxiliary operations and waiting, as production awaits the other parts for assembly and current work phase stands. Berkhahn and Miyakawa mention that these auxiliary operations are tool set-up time, programming, and program downloading, workpiece transfer, and checking processing. From that point of view, the most effective way to increase profits is to reduce the non-value-adding time.

A second aspect is to look at the cost of materials for increasing returns. Sun (2002) refers to a research, made for Lillback (Eskola & Parviainen 2000), in his thesis and summarizes a few main cost structure aspects. He states that the material cost and namely the cost of the stock sheet forms a large proportion of the total production cost, as the product itself and the production process provide a guideline for the total costs. Normally, this varies from 40 to 60 per cent of the material value, and with some alloy materials it may exceed 90 per cent. The material costs are so high, which supports the argument that nesting can reduce the product cost with high sheet utilization. Other production cost comes from NC machining, machining and maintenance, costs of labor, tools, gas and laser, equipment investments, etc.

The company has bought a new laser cutting machine recently and it will be introduced soon. From that point of view, it makes sense to look at the cost of the laser machines. Kujanpää et al. (2005, p.335–347.) discuss in their book the laser investment and operating costs of the laser cutting machines. They explains that the financial viability of the investments has raised an important measure of performance in return. Compared to conventional production methods, a large investment and high operating costs must be justified by economic considerations and advantages. Whether the laser machine provides financial interests, it can be impossible to say. However, it can be said that carbon dioxide laser is the cheapest method for two-dimensional laser cutting, where most of the operating costs comprise of gas and electricity consumption. From the perspective of investments, the most important aspect is to pay attention to the operating rate. The machine can be rarely used at full capacity, the operating rate is usually around 50 per cent.

3. INFORMATION AND OPERATION MANAGEMENT TOOLS

This chapter clarifies the basics of information and knowledge and introduces the tools for information management at a theoretical level. In addition, the role of these tools in information management will be considered from the sheet metal process point of view. The tools used in managing information are presented, including the Product Data Management system (PDM), Enterprise Resource Planning system (ERP), and to an operative level connected Computer-Aided-Design software (CAD).

3.1 Basics of information and knowledge

Firstly, the terminology must be clarified between data, information, and knowledge. These terms are very often confused when talking about information and data content. The terms are not synonymous but are often assimilated with each other. Rainer (et al. 2015.) handle information systems in their book and divides the terminology as follows. **Data** refers to the content of facts that is directly observable or verifiable and includes the elements that can be recorded, classified, or stored but are not organized for a specific purpose. **Information** refers to analysed data that provides meaning and value for the recipient. These two contents form **knowledge** where data and information are processed to provide understanding, experience, and accumulated learning. Young (2008, p. 2−4) adds that knowledge is something that only humans can possess. He also explains that knowledge is something that leads to action, also the synonym term know-how can be used. This includes content that allows us to form understanding of what is being done and how it is done. This content can be clarified with Figure 17.

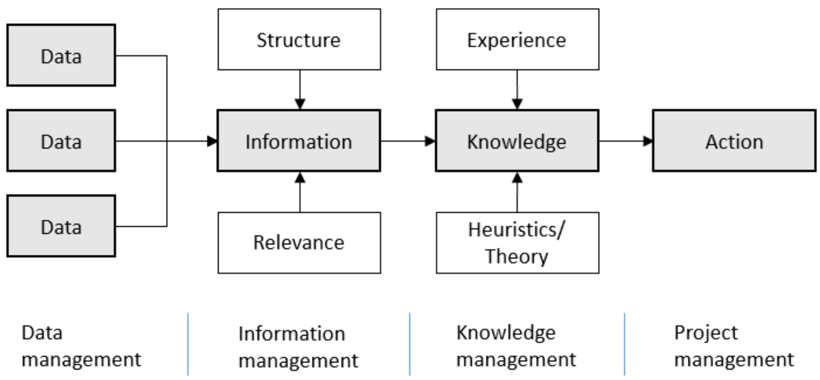

Figure 17. *The data – information – knowledge – action link. (Young 2008, p.3, modified)*

In Figure 17 are shown the previously mentioned areas of knowledge and the terminology used to managing these subdivisions. In this thesis, the content will be tied to the following three areas: data management, information management and knowledge management.

In the literature (Dalkir 2011, Young 2008), knowledge management has been widely discussed both in theory and practice. The literature divides knowledge types into two categories, tacit and explicit knowledge. When talking about knowledge, these terms are usually used. According to Young (2008), Nonaka and Takeuchi were the first to classify knowledge with these two parts in 1995. The original definition for the terms was, ‘unable to be expressed’ (tacit) and ‘able to be expressed’ (explicit). Young also explain that they are now obsolete and replaced by the following, ‘knowledge that has not been codified’ and ‘knowledge that has been codified’. Dalkir (2011, p.9, 10) clarifies these definitions as follows: “*Tacit knowledge is difficult to articulate and difficult to put into words, text, or drawings. Explicit knowledge represents content that has been captured in some tangible form such as words, audio recordings, or images.”*. Young (2008) has also presented the definitions of ‘head knowledge’ and ‘recorded knowledge’, which well describes Dalkir’s view.

In this thesis, it is essential to look at the sheet metal process and to discover committed information and knowledge between the production stages. In the process mapping phase, attention should be paid to the systems where information is embedded and their information content. In the target company, the information technology systems are focused on information management and data management. Currently, several systems are used for information management for design and production, and some of them are presented in the following subsections.

3.2 Product Data Management (PDM)

The product data management system (PDM) has been developed in order to provide a tool for product data management throughout the product lifecycle (Sääksvuori & Immonen 2002, p.13). The target company does not have the PDM system but its implementation is currently underway. Hautamäki (2014) has studied in his thesis change management of product design in the target company. At the same time, he addressed the PDM implementation into the current design environment. This thesis will not focus on the PDM system but its basics are presented in this context.

The core of the PDM is to create, store, and save information connected to the products of the company. The task is to help the company’s daily operations by facilitating the availability of product information. In this case, the processing, distribution, and re-using the product information is facilitated, thus enhancing the design productivity. The product data management also allows version and revision tracking of the product, which is a significant boost compared to the current one. (Sääksvuori & Immonen 2002, Peltonen et al. 2002.)

According to the literature (Peltonen et al. 2002, Sääksvuori & Immonen 2002.), the product data generally refers to all technical information related to the products. Product data management systems have been developed for the handling this information. These systems are commonly used to managing design data, even though they are suitable for transferring other data. This is also reflected in the fact that systems support different versioning, inspection, and acceptance policies. Generally, product data management can be divided into the following main areas: title management, document management, product structure management, and change management (Peltonen et al. 2002).

Generally available enterprise resource planning systems (ERP) have also been created to integrate the functions related to product data management. Nevertheless, there is a need for the parallel use of systems PDM and ERP. These systems comprise of duplicate management, so from the company's point of view, it is sensible to create boundaries for the data to be included. However, this is not the case in this thesis. (Peltonen et al. 2002, p.10, 11.)

3.3 Enterprise Resource Planning (ERP)

Enterprise Resource Planning (ERP) is a system designed to improve the information flow of the complex enterprise structure. The complexity of the company is formed from various functions such as purchasing, production, distribution, sales, human resources, finance, and accounting, where information needs to be shared between different functions. To this end, the ERP systems have been developed based on previous development stages of the Material Requirement Planning system MRP and Manufacturing Resource Planning system MRP II, where the MRP offered a demand-based approach for the planning manufacture of the products and ordering inventory, and MRP II added capacity planning that could schedule and monitor the execution of production plans. Later, the manufacturing execution system MES was embedded in the MRP II system providing the ability to adapt production schedules to meet customer needs and additional feedback with respect to shop floor activities. (Fortu 2002, Sumner 2014 and Stevensson 2009.)

According to Stevensson and Fortu (2009, p.668−675, 2002, p.13.), the enterprise resource planning is a system that integrates internally used software of the company into one information system. In this case, the departments and constituent groups can use the real-time information on products and the manufacturing process. The system is built from modules that are tailored to meet the needs of the company. These modules support processes and practices where the areas to be considered are manufacturing, order entry, accounts receivable and payable, general ledger, purchasing, warehousing, transportation, and human resources. Software-enhanced information flow created a general view of the process makes making decisions and monitoring the process much easier.

From the thesis point of view, the data embedded in the ERP and the possibilities for enhancing its data transfer should be studied. At present, the design data collected for the

ERP are the Bill of Materials BOM and information on production methods. Now we need to find out how and what information is collected and how it is used in production from the sheet metal process point of view. At the moment, the logistics department prepares the CNC block for the programming department based on the data of the ERP, where the CNC block is an .xls file and contains the title, material, thickness, and quantity of the parts that will be produced. This is a good example of the use of embedded data in the current production process.

A manufacturing execution system MES can be used as a link between production and the ERP system. This system is used to managing the operational operations of the production and to transmitting information between the ERP system and factory automation. At the same time, the system allows the monitoring and tracking of manufacturing aspects such as progress, resource, maintenance, and quality. The core functions of the MES systems are: planning system interface, work order management, workstation management, material movement management, data collection, and exception management. (Fortu 2012, Naedele et al. 2015.)

The PDM and ERP equivalence can also be mentioned in this section. According to Sääksvuori & Immonen (2002, p.66, 67.), the PDM system has traditionally been the main system for product information producers such as product development, and the ERP has been aligned with users like production. PDM is a management system for product titles and name structures but seldom with inventory or order backlog. These are managed with enterprise resource systems excluding the basic information on the titles that is usually managed with PDM system. Usually both two systems are linked to each other.

3.4 Computer-Aided Design (CAD)

As previously mentioned, computer-aided design (CAD) forms a support for design. According to Chang (2006, p.98–103), this computer-based process allows designers to create and edit design models and drawings with a software that serves as an interface between design and manufacturing. The needed information is included in the design model and available for the next process phases such as part programming, machining, assembly, etc. These CAD programs provide a visual design environment where all the design geometry features such as lines, circles, curves, etc. are graphically provided for the designers. Also drafting functions are available, which allows even easier and more flexible design with three-dimensional models but also with two-dimensional models.

Stevenson (2009, p.155, 156) brings up the benefits of CAD design systems and explains that they have an increasing effect on productivity. He presents a rough estimate that productivity can be three to ten times better when it is compared with a conventional drafting. Additionally, he explains some important aspects from the operation and information point of view. The design model includes important information that can be supplied, such as product geometry and dimensions, tolerances, material specifications, and this can be stored into the database. Groover (2008, p.717) explain that the functions of these databases are often managed by a product data management (PDM) module. The PDM systems provide a connection between the user and the database where it manages the transferred data. He lists that the system registers the identity of users, facilitates and documents engineering changes, records the history of engineering changes on each part and product, and provides similar documentations functions.

Additionally, Stevenson (2009, p.155, 156) states that the CAD systems also provide the possibility to determine the weight or volume of the designed part or product, and allow to perform analyses, e.g. the stress analysis of the part. The previously mentioned factors allow an effective and rapid way for comprehensive planning.

This thesis focuses on the sheet metal process from the programming point of view, and due to this, a complete discussion of CAD design is not necessary. Instead, it is more important to focus on methods that should be taken into account already in the design phase. These are unfolding and the grain direction of the sheet, presented in this section.

In older CAD software, the sheet metal design tools have been a separate module, but nowadays integrated into the software. The situation is the same with the Inventor design software. In addition, in the case of the target company, sheet metal design is the most important part of the design process. For this reason, it is necessary to introduce unfolding and corner reliefs in this context.

Unfolding or flattening

Unfolding or flattening is an operation done with a CAD software. The bent sheet metal part of the 3D world is bent open into a single sheet surface. In 3D CAD, this unfolding operation takes into account the allowance, connected with material properties, but in 2D design the situation is different. In 2D design, the designer needs to use the knowledge information to form a contour that corresponds to reality after the bending. In this case, the designer must manually calculate the changes in the length of the sheet in bending. The allowance is presented in Chapter 2.5.4. (Liu & Tai, 2007.)

Corner reliefs

The bending of the sheet metal parts must be facilitated in the design stage where the corner relief is placed in the bending line intersection. Matilainen et al. (2011, p.259) explain that the corner reliefs have to be done because it allows the bending of sheet metal parts at the corners in different directions. The round reliefs prevent corners from tearing, making the structure more durable and reliable. The shape of these corner reliefs varies depending on the situation. In the company, the use of these corner reliefs is based on experience and manufacturing methods. Figure 18 shows an example of the relief shape used by the company.

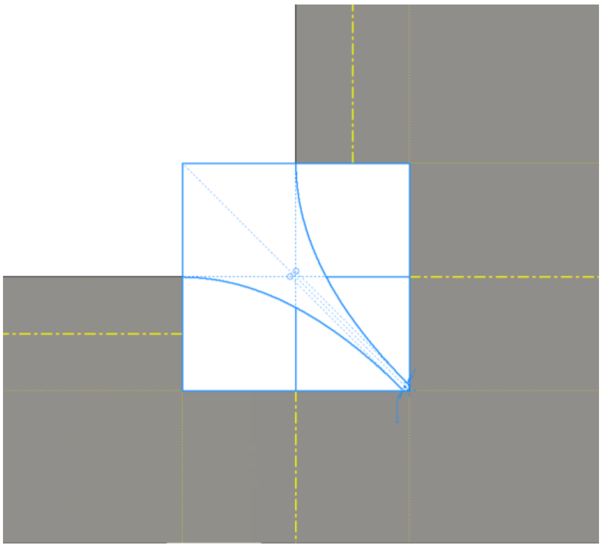

Figure 18. An example of experience-based corner relief used in corners of the sink.

The corner relief presented is used with sinks and large inner tanks of the counter bodies. This is just one example of the shapes, but all of them have to be added manually into the model.

Grinding direction of the sheet metal

For the products manufactured by the company, it is important to know the grinding direction of the sheet metal part. The grinding direction of the part has an impact on appearance, which is why it has to be managed. This ensures that all parts are compatible with each other. At present, the grinding direction is manually marked with macros. This will be discussed in a later chapter.

4. CURRENT SITUATION

SeaKing is a global company that designs and supplies complete catering systems for cruise ships. The aim is to implement the customer's vision by offering them products and services competitively and profitably. The company's design work is mainly focused in Finland where the planned products are ordered from SeaKing's factory in Poland. This thesis will focus on the design work of production from the point of view of sheet metal process. The main target is to keep focus on information flow management in the NC process.

The design starts with a concept design phase that supports sales and later leads to comprehensive furniture design. Furniture and layout design in Finland work in close cooperation with customers, aiming at ensuring the customer's satisfaction. In new building projects, the buyer is usually the owner who orders the ship from the shipyard. Nevertheless, furniture design in Finland mainly cooperates with the shipyard.

The main task for furniture design is to implement a functional entity that serves both the shipyard and the shipowner. This requires taking into account ship structures, architectural perspectives, and customer requirements. All this has to be done in strict compliance with the requirements of the health authorities in relation to ship hygiene that will require additional design effort. Because of that, design is divided in two organizations where the first is the layout and furniture design in Finland with a close customer cooperation, and the second is the manufacturing level design in Poland.

In short, Finland will order the product from Poland, where the product will be designed according to geometry received from Finland. Then Poland will design and produce the product with the available manufacture methods. The order proceeds through the logistics department to the design department and from there to the production.

A key part of this thesis is the sheet metal process from the NC point of view with its related information flows. The NC process is strongly associated with the programming department between design and production. The task of the programming department is to produce a blank for the production from which a sheet metal part will be completed in later stages of production. These blanks are currently cut from the sheet metal by laser or by punching, using a program made by the programming department. The company has two combi machines with laser and punch features, and a new laser machine with unloading equipment will soon be brought into use. Each of these machines will require programming to produce parts. In addition, several NC programmable press brakes are used but they do not utilize the potential benefits of offline programming.

Now, the laser to be introduced will require a new nesting software, so it is time to consider setting up a new nesting into the current process model. The punch function of the current two combi machines has been an addition to modifying the sheet metal sheets. With the new laser machine, the company will need two separated programming software for programming. That is because parts for the new laser machine must be programmed with different software than parts that go to the existing combi machines. These machines are made by different manufacturers whose requirements are related to the guarantee of the machine by the manufacturer. Both machines could be programmed with a third party's software, but this may not allow efficient use of the machines. In these cases, the machine manufacturer has not offered support to the software where all the possible properties of the machine would be allowed. Now it presents a challenge of how to manage information where the designed parts are connected to the machine base. The main question is: what kind of information should be included in the system and how to differentiate the programmable parts.

In the current situation, the design department has three different CAD systems from which the design information is distributed to production. The implementation of a new CAD system is underway in order to improve sheet metal design and reduce the parallel use of existing software. In addition, the aim is to extend the new CAD environment to Finland as well, enabling Finland to use existing design as a basis for new products without having to redesign the whole product. The target is to eliminate duplicate work, hence reducing non-productive work.

4.1 Available systems

This section introduces the design software used by the company and the software services that support it. At the moment, there are plenty of design software, which is a challenge for data management. Data transferred between the software has to be modified several times when data is transferred from one program to another. There is a risk of some information disappearing along the way or, alternatively, the edited information in an earlier stage cannot be processed later. In the worst-case scenario, we are faced with a situation where work has to be redone and overlapping of work cannot be avoided. Because of this, it is important to focus on one product family of design software. At the same time, the aim is to harmonize the Finland-Poland design and the new PDM system. Above all, this is the objective of reducing the duplication of work. The software used by the company and their file formats are shown in Table 1.

Table 1. *Used software and their file formats*

		Used file formats		
Software	**Description**	**Native**	**Export**	**Import**
CAD				
Bentley Microstation	2D, (3D) design	.dgn	.dgn/.dwg/.dxf/.pdf	
Pro Engineering	3D design	.prt/.asm/.drw	.dwg/.dxf/.pdf	
Autodesk AutoCAD	2D design	.dwg	.dxf/.pdf	
Autodesk Inventor	3D design	.ipt/.iam/.dwg	.dxf/.pdf	
Programming				
NC Express	NC programming Finnpower			.dxf
TruTops	NC programming Trumpf			.dxf
Add-in				
LinkIT (ProE/Inventor)	Data link, CAD <-> ERP		.xml	

At the moment, there are three design software used in the design department and two of them are intended to be replaced. This is executed step by step when the Autodesk Inventor 3D design software will be turned on. The use of software that have been presented in Table 1 is divided as follows.

Bentley Microstation

Microstation is a 2D/3D CAD software and currently used in Finland and Poland. In Finland, all design is done using this software in which layout design is carried out with 2D seed and furniture design with 3D seed. The furniture design of Finland forms a geometry for the product that is ordered from Poland. According to this design geometry, the design department of Poland will make a new design so that the product can be manufactured. The product design is divided into two sections, 2D and 3D design, where the used method depends on the product being manufactured. So far, the table tops and some frame structures are designed with 2D seed using the Microstation software. Otherwise, the design is done by using the Pro E 3D design software.

Pro E Wildfire 4.0

Pro E is a CAD software used in 3D design and it will soon be disabled. The software is used for most of the mechanical constructions such as the structure of the drawers, canopies, hoods, and refrigerator assemblies. The advantage of 3D design is the dimensional accuracy of sheet metal parts in which unfolding is done by using bending tables. This has enabled an accurate matching of sheet metal parts compared to 2D for computational and experimental flattening. In addition, the consideration of experience-based forms on a library basis has increased the design efficiency. At the same time, the flattening shapes or dimensions learned from the 3D world have been used in 2D design together with the Microstation software.

Autodesk AutoCAD

Autodesk's AutoCAD software has been used to processing and generating design data for the subcontractors. From the sheet metal production point of view the existence of this software can be ignored.

Autodesk Inventor

Autodesk Inventor is new 3D CAD software that will replace the existing Pro E in the near future. After this change, the intention is to move from doing design with Microstation to the world of Inventor. The implementation of this software is in progress and if the benefits of the software prove to be positive then the use of this software can be expanded to include the furniture design in Finland.

NC Express

NC Express is a software for programming and nesting and it is used for two Finnpower laser and punching combi machines. The software is currently used in the programming department where three programmes produce the required software for the machines. This is done according to the design data, which is shared by the design department in .dxf format. In the future, this software is not suitable for programming with the new Trumpf laser machine, therefore Trumpf's own nesting software is needed.

TruTops

TruTops is a software for programming and nesting and it is used with the New Trumpf laser machine. This new CAD/CAM software provides the ability to edit and program sheet metal parts separated from the other design software. It may offer an advantage in producing individual parts or repairing an incorrect part before programming and nesting. The software also makes it possible to import 3D parts in several formats. These parts can be unfolded inside this program without requirements for the CAD software. Nevertheless, the parts for manufacturing will continue to be imported in .dxf format.

LinkIT

LinkIT is a tailored software add-in that enables BOM data exporting and creation embedded in the ERP system. The add-in also enables the design file editing with macro scripts, for example naming the products and adding descriptions to achieve uniform naming. It is also possible to publish design documents as a mass drive with this additional part.

4.2 Transition to the new system environment

The company is renewing the CAD environment in the Poland factory and the implementation will be performed within a year. This means the introduction of a new CAD design software in which the existing Pro E and Bentley Microstation 2D/3D software will be replaced with Autodesk Inventor. Microstation's software will be partially retained as a design aid until the new system has been fully embedded. At the same time, a PDM system that the company has not used before will be implemented. The previously used PDM system in Pro E has been used to managing the 2D drawings created with the 3D model within the software. The system currently being implemented is intended to greatly improve the management of product information. The objective of the future is to start using only one CAD software instead of the present three. Additionally, the implementation of the new laser machine will require a new programming software to support nesting. This system environment change is illustrated in Figure 19.

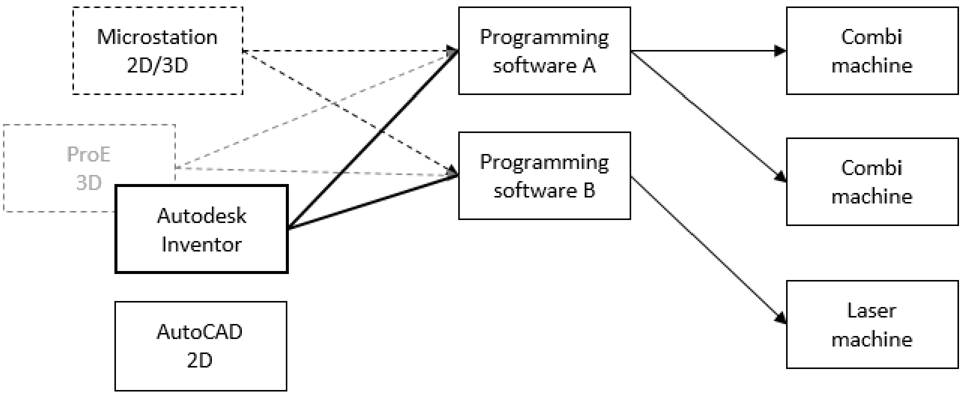

Figure 19. *CAD system environment from NC programming point of view.*

Due to the current machine base, the number of programming software will increase from the current one to two. The current NC Express software will be kept for two of the existing combi machines programming and the new Trumpf TruTops software will be implemented with the new laser machine. For the company, the key factor will be how to effectively import design data into the programming environment and what are the factors that need to be taken into account in data management. Also for the production of the blanks it is essential to know what parts are going to laser cutting and which ones require the tools of combi machines. Incorporating this information into the current production system will be particularly important.

With regard to the new systems, it is relevant to consider how information on the grinding direction of the sheet metal parts could be included in the information systems. The aim of this perspective is to avoid manual work. In the present systems, the grinding direction is marked manually or by macros into the production drawings. Later on, the programmer will manually rotate the part according to the grinding direction of the sheet. The new systems environment could provide a solution for including this data to the production systems, which would allow partial automation of the process.

At a later stage, consideration should be given to the alternatives embedding the CAM systems into design work. Now the design department produces design documents for the product, from which programmers will adapt the information according to the machine base and the needs of the manufacturing methods. This could lead to a situation in which design could more effectively take into account the existing machines to intensify production. An example of this is are the currently available NC programmable press brakes that are more or less manually used by operators.

4.3 Increasing the machine base

As previously mentioned, the company is increasing the number of its cutting machines from two to three in the sheet metal process. A new Trumpf laser machine will be installed next to the two existing Finnpower's combi machines. The new Trumpf laser machine will include an unloading table for handling sheet metal parts. The machine unloads the parts automatically and detaches the parts from the nest. Compared to the two previous machines, this does not need any micro-joints to hold the workpieces on the sheet. Thus, the removal and unloading of the pieces will be greatly enhanced when time is not tied to the removal of the parts. At the same time, the sheet metal parts are released much faster for the following production stages.

The new feature is that the new laser machine allows sheet metal parts labelling with a laser. An option for this feature has been acquired but its use should be investigated so that the marking trail is sufficiently good and clear. The most important thing is to achieve a clear label that survives throughout the production without the risk of losing the part number during the manufacturing process and, additionally, that the label stays on the nonvisible side of the ready product. Currently, the products are manually marked by the operators according to the laser reports and sorted into trolleys to wait for the next production stage.

As mentioned in Chapter 2.3, the bending process forms a productions bottleneck due to the production-efficient laser and punching machines. The new laser machine will further increase cutting capacity, which may appear as a buffer before the bending. It remains to be seen whether the laser cutting capacity is too large in relation to the bending. When considering the situation before the acquisition of a new laser machine, the needs of the production required that one additional machine had to be purchased. The capacity of the two existing combi machines is not enough and with three it is potentially too large. Because the new laser will be more efficient than the old ones, it would be worthwhile to cut most of the parts on the new laser and, if necessary, increase the use of the older machines. On the other hand, we are in a situation where production by three machines is possible in two shifts instead of three. In this case, it will be considered whether it would be cheaper to run machines in three shifts with fewer staff than to run three machines in two shifts.

5. MAPPING THE SHEET METAL PROCESS

Based on the literature review and the interviews, the chart for the sheet metal process of the company was formed. The process flow charts were formed based on CAD design, part programming and nesting, cutting and bending. These flow charts were formed by presenting the key work phases of each process by linking the relevant information flow between different services. The flow charts were designed to be as realistic as possible based on the interviews and the findings collected during a visit to the factory. Such a realistic diagram provides an opportunity to identifying the disadvantages as well as addressing them. In the generated process flow charts, Appendixes B−E outline the potential problems and related factors in the process. These processes and their core contents are presented in this chapter.

5.1 Design process

SeaKing's Polish production is scheduled by the logistic department that receives orders for products to be manufactured. After receiving the order, the logistic department schedules the order according to the needs of manufacturing to match predetermined delivery time. At the same time, the department prepares a production plan for the product that serves as a tool for production control. In practice, this .xls document contains all data related to the scheduling and coordination of the production.

The actual design process starts when the design data of the product arriving from Finland is handed over to the logistic department where the design data is transferred to the design department. The received drawing is called a main dimensional drawing. At the same time, the date of arrival and revision of the drawings is recorded into the production plan. The design data from Finland includes a 3D design data of Microstation in native .dgn format. The file contains a 2D drawing generated from the 3D model and where the design data includes the necessary details and dimensions. This file constitutes the framework for the design in Poland where the purpose is to design the product according to the geometry defined in Finland.

Based on the order from the logistic department, the design department prepares for each item a new work folder in the database where the design data from Finland is copied to. This item-based folder is moved into a project-based workspace folder where all project-specific design data will be collected. These files are managed manually in the Windows explorer folder view. There is no available PDM system in Poland for managing the design data, which means that the Windows time stamp is the only tool for managing the document versions. A time stamp is the only factor with which a new or old version can be distinguished in the current system. What further adds to the challenge is the fact that the name of the drawing is preserved through the process, and how the new and old files should be separated from each other.

In design in Poland, the designer is responsible for the assignment from the cradle to the gate. The designer receives information on the product's production schedule and situation in the production plan, which allows the designer to schedule his work. It is also possible for the designer to check the latest revision of the drawing received from Finland that the design is based on the most recent revision. If there are any changes to the product revisions, the designer gets this information via e-mail from the logistic department, after which the responsibility for the changes of the products has shifted to the designer.

As mentioned earlier, computer-aided design is divided into two parts depending on the product being manufactured. These design trends are 3D design with Pro E or 2D design with Microstation. At present, design is based more or less on the parallel use of these programs to the producing required by a single product.

5.1.1 2D design with Microstation

Currently, the design with Microstation includes the production of the table tops, foundations, and some parts of the furniture bodies. In practice, the designers convert the 2D elevation from the 3D drawing produced in Finland. As an example, in design of the table tops, the designer removes extra features from the converted elevation. This aims at the situation where only the contours of the table top remain. After that, the designer starts the flattening process with the learned rules. In this case, the designer must take into account the desired shape, sheet thickness, empirical shapes such as rounded corners, and available tools in production line. The manufactured products are essentially plain and the used patterns are repeated from furniture to another. The designer's task is to evaluate the length of the flanges and to draw the midlines for the bending.

When the contours of the sheet metal part are designed, the designer adds corner reliefs to the drawing by using the macros integrated into the software. The macros have been produced and edited using the features learned from the 3D design software and based on empirical knowledge. Experience-based shapes take into account the manufacturability of the products, as exemplified by the wash sink shown in Figure 20, where the rounded corners have been modified to fit in the manufacturing process.

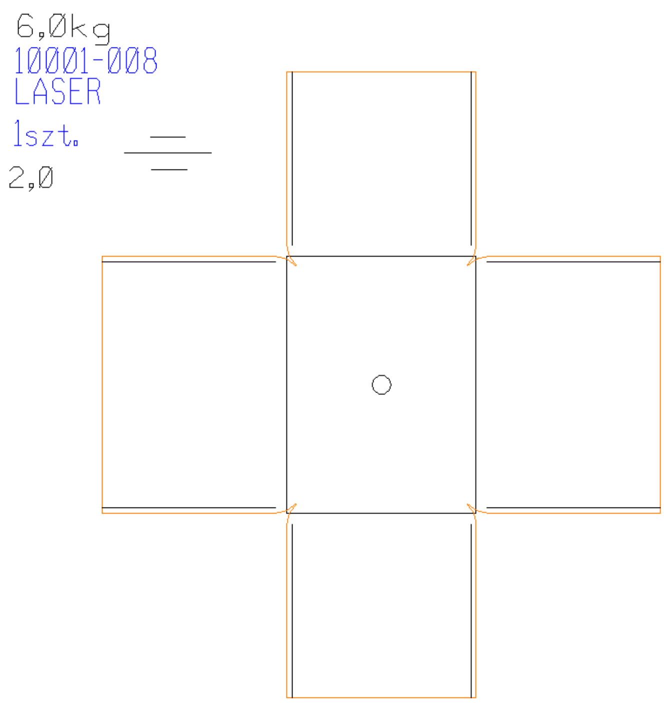

Figure 20. *Using of empirical shapes on flattening process based on manufacturing methods.*

Macros are also used to adding mark of the grinding direction, part numbers, and weight of the sheet metal blanks. An example of a macro-filled workpiece drawing is shown in Figure 21.

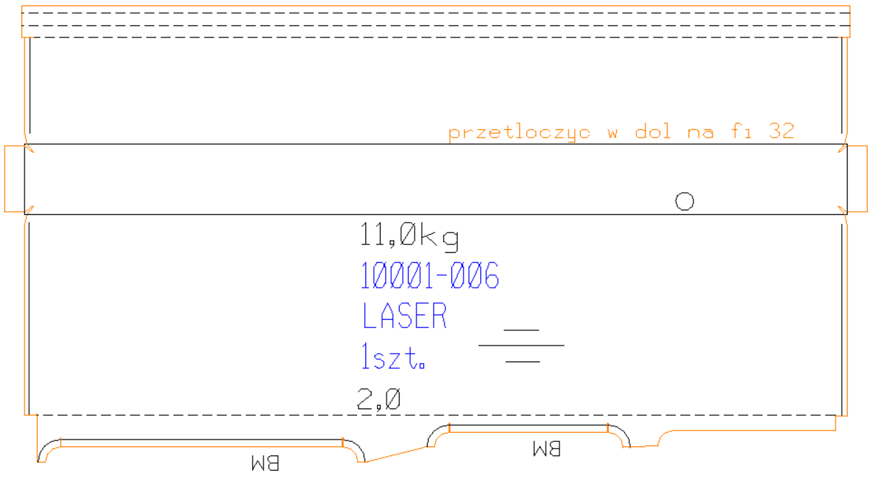

Figure 21. *Macro-filled workpiece in a bending/.dxf drawing without dimensioning.*

The grinding direction is marked on the sheet metal blanks so that the blanks can be positioned correctly on the sheets. In addition, the maximum size of the sheet to be cut is determined by the grinding direction, since the grinding direction defines the orientation of the sheet. At the same time, the sheet to be used determines the maximum dimensions of the sheet metal blanks. Usually in one Microstation 2D drawing, there are several pieces of sheet metal blanks in which the grinding direction varies according to the sections to be cut. This information is not included in any information systems, so each piece must be rotated manually in the correct way. The pieces can be rotated at 0°/180° or 90°/270° with respect to the grinding direction.

In the design department, three drawings from the ready production drawing are published. Two of them are the bending drawing and the .dxf file that are necessary to publish to the programming department. The generated .dxf file is stored into the .dxf folder located under the working folder of the project and from which the data is available for programming. In addition, the bending drawing is located in the production folder under the project. The third part to be published are the assembly drawings that are located in the production folder and copied to the production drawing. This production drawing is a file that contains all drawings from both Microstation and Pro E, and it is placed under the production folder.

The designer assembles a BOM list based on the completed drawings and after this, the information will be included in the ERP system. This list includes parameters such as the part name, material, size, and quantity, namely the data that has been collected from the drawing by macros. These macros are managed with an installed add-in, where it creates an .xls table of these parameters embedded in the ERP system. In addition, the designer creates a CNC block .xls file that includes information about all the parts that require NC programming. Currently, the parts that need programming are those that are going to laser cutting or forming with the existing combi machines. In addition, a list of these parts has been embedded in the ERP system. Other cut parts are manufactured using shearing machines, for which the designer creates an .xls list showing the title, dimensions, material, and quantity of the part. This .xls file is stored into a product-specific production folder.

5.1.2 3D design with Pro E

At present, the 3-dimensional design for production is done with the Pro E Wildfire 4.0 software. This software will be replaced with Autodesk Inventor in the near future and, in this respect, the implementation has already started. The design and related observations in this section are related to the currently used Pro E software.

The 3D computer aided design in Poland covers almost everything except the 2D designs such as the table tops, counter bodies, and foundations. Designing with Pro E is based on the design of a complete 3D model, making it easier to combine the assemblies of the products than with Microstation in 2D. In addition, the amount of design errors are lower and the products will be completed faster.

For the sheet metal parts, the design department forms a 3D model that can be unfold with the available bending tables. These tables take into account the bending radius of the tools, k-factors, material thickness, and the necessary manufacturing tolerances. Currently, the company does not use machine-specified bending tables that would take each machine, material, bend angle and tools into account.

The manufactured parts include a number of experience-based shapes, which means that the automatic unfolding does not meet all the requirements for manufacturing. Due to this, the unfolded sheet metal form will be manually corrected for each manufacturing method. Such shapes are rounded corners on the table tops and sinks as well as corner reliefs. These are shapes that cannot be unfolded automatically. Such spherical shapes and angles with a large bend radius do not unfold properly, so they must be manually corrected in the model. In practice, this is done by removing the part of the model that cannot be unfolded. Thereafter, experience-based and custom-made shape is manually added to the unfolded model. In the Pro E, the drawing is corrected by creating a drawing from the unfolded model, and the shapes from the library are placed by providing reference points for the shape. These corrected drawings are stored separately into the Pro E's internal PDM database. This also means that the information being used does not travel backwards to the higher-level 3D model. Every unfolded sheet metal part is exported into a .dxf file that is shared to the programming department. These files are stored into the .dxf folder under the project and made available to the programmers.

In Microstation, all parts of the item are included in the same drawing, but in Pro E, every part has its own drawing, which is a clear difference. The titles of the created drawings can be embedded directly in the ERP system by using a tailored LinkIT service, which is not used with Microstation. Using the same add-in service, the BOM of the assembly can be transferred to the ERP. This data includes the titles of the parts, material, thickness, weight, and quantity with the mother-child relationship.

As with Microstation as well as for 3D design, the designers incorporate information on programmable sheet metal parts in the ERP system and form an additional list where the parts for shearing are presented. According to the list, the operator of the guillotine cutting machine has enough information to cut the parts for production. All produced drawings are published in the production folder, such as bending and assembly drawings. These assembly drawings are presented also in the production drawings together with the Microstation drawings.

5.1.3 Re-manufactured products

If the ordered product is known to be equivalent to the previously manufactured, it is wise to use the drawings of the previously manufactured product to avoid overlapping of work. This can be done by copying old drawings from the database into the new work directory of the project. After that, the designer updates the content to match the new project and publishes the drawings for production. At the same time, the designer informs the programming department via email of the re-production of the project. The email contains the project and item number and usually even a package of previous .dxf drawings that have been copied from the previous project. According to this, the programming department is able to combine the information of an old project with a new subscription, without the .dxf drawings being found in the project subfolder.

5.1.4 Publication of drawings

All the design documents have been published in the production folder under each project. In addition, this data is included in the main drawing called the production drawing. The format for this file is .dgn, which combines design data from both Microstation and Pro E. From the data transferring point of view, the imported data has to be converted into the correct format in both cases. At the same time, it is a challenge for revision management. All the drawings presented in this file have been published to production by the designers.

The publishing of the design data will be done by the designer, whereby the produced drawings are printed while waiting for production and stored in the drawing locker of the production. The designer compiles drawings for each product so that they are available and usable for flat processing, bending, and assembly. Then a production worker collects the drawings from the locker to production when the production starts. At the same time, the employee checks each revision of the products to make sure that they are aligned with the production plan. The printed drawings follow the product until it is sent to the customer, but they are not delivered to the client.

5.2 Part programming and nesting process

The programming department is separated from the design department but is part of the activities to support production by programming and nesting. This department consist of three programmers at the moment. The tasks include NC programming and nesting for two existing combi machines and for one new laser machine. The schedule for the programming is given by the logistic department that prepares the order-based CNC blocks for programming. This CNC block is an .xls file and contains the title, material, thickness, and quantity of the parts that will be produced. The content of this file is generated from the ERP, where this corresponds to the production's needs based on scheduled delivery time. In practice, this file is the order for the programming and distributed via email.

Each item in the production plan has a CNC block number and according to this information, it is possible for the programmers to combine the order from the logistic department with the production plan. The guiding factors that are marked in the production plan are the delivery time and the planned starting date for production. Based on this information, the designer prioritises his own work of programming. The programmer is also required to update the production plan as the work progresses, where the topics to be recorded are, for example, the starting time for the programming and the release date of the finished program.

With the current NC Express software, the programmers open the .dxf file prepared by the designers. The geometry of the .dxf file can be directly linked to the programming platform. Then the programmer is responsible for filtering extra content from the file and checking the size of the parts so that they fit on the available sheet. In some cases, such as large inner tanks of the counter, it may be necessary to divide the part into two parts. In such a situation, a new file will be created to enable programming and these parts will later be welded into one piece in production. An essential task for programming is to check the contours of the imported parts in order to avoid discontinuities. This is because the existing software is not capable of defragmenting discontinuities, which leads to errors in laser cutting. The observed discontinuities are a common problem with 2D design software, which have not been observed in relation to 3D design software.

After defining a successful geometry and checking the part, the programmer adds the required parameters and tools to the workpiece, depending on how the components are to be manufactured. After that, the part is ready to be saved in .cp format into a working folder called a part catalogue. The company has some standard products that do not need to be re-programmed. In such cases, if the programmable part is already in the existing library, the programmer copies the program from the standard library into the work folder. This folder contains all programs for each programming project and in other words those programs that are included in the CNC block. The contents of this folder, the programmer will transfer to nesting.

The programs that are placed into the work folder will be nested according to the CNC block published by the logistic department. This list contains the material, thickness, and quantity for the programmable parts. In addition to this, the programmers have a list of the inventory that includes information about the material situation in the warehouse. Based on this knowledge, the programmer will fill the sheet with the best possible sheet utilization. In nesting, the grinding direction of the parts needs to be take into account, which forms a challenge for the sheet utilization.

The programmer must take into account the size and material of the sheet metal for nesting. Only the parts with the same thickness and material requirements can be placed on the same sheet. The material of the parts is presented in the CNC block, supplied by the logistics department. The programmer chooses a suitable sheet for each nest according to that information. Additionally, the programmer has to take into account the orientation of the parts. The parts to be cut have been placed in the nest according to the grinding direction from which the information has been included in a .dxf file. Based on this information, the parts can be rotated either 0°/180° or 90°/270°. This work is done manually, as there are currently no possibilities to automate the reversal of the parts. Nevertheless, with the current nesting software, it is possible to rotate more than one part in an import phase, but in this situation it should be ensured that the parts are orientated in the file in the same way.

Sometimes the programmers are faced with a situation where programs need to be done for individual parts. In this case, the parts are nested on the custom-sized sheets for better sheet utilization. Information on the size of the sheets comes from the production and specifically from the operators of the guillotine who manage the so-called “waste deposit” stock. The programmer provides the information on the nested parts and their dimensions and the materials, and the production returns the information on available material and sizes. This is done if there is suitable material available in the “waste deposit” stock, in other cases the full-size sheets are used.

The finished nest needs to be post-processed into a readable form for the machine. Then the program will be stored in the database from which it is available for the combi machines. From this database, the operator can download the program to the production machine during the manufacture. When the programming block is completed, the programmer marks on the production plan the time when the program is completed. At the same time, a report of the material utilization is generated into an .xls table that will be shared to the logistic department. This report includes information on the use of material such as the quantity, mass, and dimensions of the used sheets. In addition, reports of the nests are generated and shared for the operators of the production.

The information on possible changes to the existing programs is available in the design department via email. Typically, a design change of already programmed parts needs to be re-programmed before laser cutting. In cases where the parts are already produced, the new program to be redistributed is based on shared information. It can also be an update of the new standard product that enables the programmer to include the information content of the program in an already existing standard library. In such a case, it is an update to the previous produced standard product. The designer contacts the programming department via email that includes the path for the new .dxf file and related information for the update. The programming department also receives feedback from production. In general, incoming feedback refers to missing parts or other production errors associated with programming. These include, for example, laser cutting errors in which the program cannot be downloaded onto the machine or the program does not start.

5.3 Laser cutting, punching, and shearing process

The manufacturing of the sheet metal blanks before the introduction of a new laser machine has been carried out with two combi machines with laser and punching features, and with one NC programmed guillotine. In this environment, the work is divided between the machines as follows. All the rectangular parts are cut with the guillotine according to the cutting list made by designers. The cutting list includes the dimensions, material, and quantity of the parts to be cut with the guillotine. The other parts are cut with the laser machines.

The operator of the laser machines receives information on the parts from the laser report, which of them needs to be cut. This report includes the following information: the part name, the program, and the material for the parts. The operator downloads the file from the database onto the machine control unit and inserts all the needed parameters to perform the cutting. At the beginning of the cutting operation, the operator starts to prepare the next program while the other operator performs the unloading of the parts. Each cut part is removed from the nest and marked with a part number according to the laser report. Then the parts are sorted into trolleys to wait for the next stage of production.

The operator is required to report any errors in the cutting process to the programming department. The errors to be reported are error situations, missing parts, or incorrectly produced parts. Notifications are mostly made by phone or face to face. After this, it is the programming department's responsibility to correct the errors.

The operators also take care of recycling waste material. The largest pieces are moved to the material storage next to the guillotine where they are "re-used" when material is needed. As an example, the previously mentioned nesting of the individual parts in small custom-sized sheets is made in cooperation with production and programming. In addition to this, the operators take care of overall cleanliness and possible maintenance work that can be managed at operator level.

5.4 Bending process

The bending of the sheet metal parts forms the next work phase after the manufacture of the sheet blanks. The company has five NC programmable press brakes for bending, operated by about 20 employees. However, remote programming is not performed, as the machines are manually operated based on the experience-based knowledge of the operators. Nevertheless, the operators have created their own programs where the most commonly used shapes are parametrized. These programs are used, if possible, for manufacturing products in accordance with the drawings.

The operators of press brakes pick up the sheet metal blanks cut with the laser and check that every part is bent according to the laser report. In addition, the operators have item-specific drawing packages that include the bending drawings for each item. Based on these drawings, the operators choose the right tools for the bending. The choice of tools is based on experience and knowledge, because tools are not specified or marked in the drawings by the designers. The press brakes are parameterized based on this knowledge and information on the available drawings. For bending, the most important information includes the location of the backgauge, the bend angle, and the press force, which are calculated with the machine control unit based on material information and inserted parameters.

At this moment, the bending is done step by step and with batch production if possible. This means that if there are similar parts in bending, then the bending has to be made before the transition into the following bend stages in order to minimize tool changes. In this case, the parameters of the press brakes are chanced after all similar parts are bent to the same shape. This means that the bent product will be released to the next stage of the production after the last product of the series has been bent.

After bending, the produced parts are compared to the drawings and the main dimensions are checked. If the bent product corresponds to the part shown in the drawings, it can be released to the next production stage. The operator is obliged to inform all detected mistakes.

6. CHALLENGES AND DEVELOPMENT

Based on the mapping of the current sheet metal process, flow charts for the most central processes have been generated. The flow charts are presented in appendixes B−E. Based on the research, potential possibilities for errors and challenges for the sheet metal process have been mapped out and presented in the flow charts. Based on this, the most challenging aspects of the sheet metal process have been highlighted with themes. The most challenging areas to the process were information flow problems, human based errors, revision management, and manual non-productive work. Additional observations were related to extra work and inadequate knowledge of employees.

6.1 Information flow errors

The key challenges to the information flow are both communication between the employees as well as the information flow between different software. The challenges of information transfer between the software arise from the data converting and importing from one system to another. Between the employees, the factors that affect the information flow errors are mainly connected to the communication methods or to the lack of communication.

The biggest challenge to information transferring is the 2D design with Microstation software where the problems are related to both software features and behaviour as well as to design. In Poland, a 3D model designed in Finland will be converted into a 2D form. This is because the created 3D model cannot be utilized in Microstation's sheet metal design. This software is not suitable to unfold 3D models, so the work must be done manually. In such case, the designer starts the sheet metal design by defining the dimensions, key features, and shapes of the product by editing the converted 2D model. From this 2D model, the designer separates the contour of a product by manually removing extra contour lines. This is due to Microstation's way of creating additional contour lines and discontinuities when the model is converted from 3D to 2D. The software is not able to correct these disadvantages automatically. Manual manipulation poses a risk of losing important features, which would distort the shape of the model. Another important and significant aspect is the continuity of the surface contours. These discontinuities are currently causing problems for the programming department, as the contours have to be repaired manually in each .dxf model. If these are not corrected, a laser cut error might occur where the beam of the laser pierces the desired area. Basically, the design should produce an intact .dxf file that no longer needs to be repaired for the programming department. The beginning of this problem can be found in the data conversion, so this is not just about design error.

This contour problem will only be eliminated when the new Autodesk Inventor design software replaces Microstation in sheet metal design. The ongoing Inventor implementation project will initially override the existing Pro E software, after which the aim is to move step by step from Microstation to Inventor. The reason for the slow transition from Microstation to the newer and more modern system is the change resistance experienced both in Poland and in Finland. The target of the company is to renounce Microstation 3D design in Finland after the new software environment has been implemented in Poland.

Another encountered problem related to Microstation design is the BOM data export into the ERP system. The Microstation model is not feature-based, which means that it does not include information on the material, thickness, and mass properties. In practice, this model is the flat line drawing from which the BOM information is manually created. Because of this, the BOM list is currently created by macros but it may not necessarily include the needed information such as the mass of the parts. Therefore, the embedding into ERP will not succeed. Manually correcting this information requires extra work, which should be avoided. These issues may eventually be removed when design with Microstation has been finished.

In the programming department, information management challenges can be found in email communication and the .xls list of the material inventory that may be not up-to-date. The examples of these two situations are presented below.

In the first case, the programming department received the order of programmable products via an email from the logistics department. In addition, information on design changes is delivered to the designers via email. In both cases, the tool for the communication is email, which constitutes a potential risk that important and possibly critical information will be lost. For example, a situation in which the design department informs about the urgent changes on the product that have to be implemented into the program. The product may already be programmed, and the question is whether the updating request will reach the original program. It is possible that another programmer has already made an update to this program, but there is no definite way of knowing that. In the current system environment, the data management is based on the Windows Explorer folder structure together with time stamps. Now, the time stamp is the only factor that allows version management. In the worst case, an updating request may lead to a situation in which the product is manufactured twice, incorrectly and correctly.

The second case is related to the material list, a file that the programmers use for getting information on the material available in the store. The programmers select the sheets for the nesting according to the list. The programming department receives the material list once a week. Based on the interviews, it became clear that material management is a challenge if the material used in the product does not correspond to the information included in the ERP. In this case, there is a risk that the buffer of stock material is not adequate or the material is out of stock. For example, the ERP information that the material for the product x is AISI 316 and the thickness is 2.0 mm, but this does not determine if the material surface should be protected with foil or not. The company should consider whether it is necessary for the designers to know which manufacturing methods require that the material surface is protected. In this case, grinded sheets are typically protected with foil. The question remains whether this is important to know. In that case, the ERP should include the complete information about the quality of the material.

Adding a new laser to the existing machine base will require the separation of programmable parts according to the machine base. This condition arises from the fact that some of the manufacturing methods will require the use of combi machines for punching and forming. These parts cannot be manufactured with the new laser machine. Currently, the logistic department prepares the laser block for the programming department and this has not been considered in regard to the manufacturing method. In future, the purely laser cutting parts will be cut both with the new laser machine and the two existing combi machines. But if the part contains the features that have to be manufactured with punching or forming methods, then the part goes to the combi machines. To accomplish this, it might be necessary to add ERP information on what manufacturing methods the part will need. It should also be noted that both of these machine types require their own programming software. Based on the ERP data, the logistics department would be able to generate machine-specific CNC blocks that are based on machinery. This would also require that the manufacturing method of the part could be decided in the design stage. Currently, the programmer decides which holes are cut with laser and which by using punch.

6.2 Human based errors

At the employee level, the biggest challenge is the know-how or its lack among the staff. At present, the designers' knowledge is largely based on memorized information on how each step should be done or how it has been done before. This is a major problem or root cause for problems that may arise or for the products that are incorrectly manufactured. These memory-based problems are further discussed in this section.

At the moment, the design department does not have a commonly used design manual that would present the use of empirical-based information in design. They have some manuals and templates on how to design products but they are not readily available or cannot be utilized. Now the requirements set by empirical shapes and methods of production must be learned through mistakes. This is not the most sensible solution, which is also recognized in the design department. The problem is highlighted in connection to staff turnover where the introduction of new employees into the design work will take a long time. Tailor-made furniture also creates a challenge, as existing work methods and standards cannot be utilized. In such cases, the furniture must be designed on a case-by-case basis, taking into account the requirements of the manufacturing methods.

In the sheet design process, the features are simple and the same shapes are repeated from one project to another. During the interview, it became apparent that the design aims to use the already designed products as long as possible without the need to redesign. This has been accomplished by copying the used features from the previously produced products in which these are adapted into the current design project. There is a risk that the design does not take into account, for example, the product's guideline and details that are produced in Finland. This product has been copied from the previous project as if it corresponds with the current project even if it's not the same case. In such a situation, a contradiction is present between a product that is designed in Finland and produced in Poland. In other words, the information produced in Finland has not been moved to Poland. At the same time, the geometry that is already produced is redesigned or copied from the previous project, which also takes time. The time used is non-productive and should be removed. This challenge is eliminated if the furniture design in Finland is to implement the same system as the Polish environment. The aim is to synchronize the design systems between Finland and Poland and to link them into a unified PDM system. After this, the published design data would be available for production as such. This would be possible if the product or part of it was already produced and placed in the design database. In this case, the design department in Poland would complete the missing parts of the product, as the whole furniture would not be redesigned from a clean sheet as it is done now.

The designers' turnover also poses a challenge in the sheet metal part design with Microstation, because in a 2D world the teaching of flattening to young designers is very challenging. This directs more effort into changing the system in which the parts would be designed with a 3D design software, and time-consuming manual flattening work that increases the amount of possible errors would be removed. As mentioned in the previous chapter, this also has an impact on the productivity of programming. Another design challenge for programming is considering available manufacturing tools in design. At the moment, a tool library is not used in design that would allow design features to be aligned with the existing production machines. Now the designer is responsible for finding the methods to manufacture the product with the tools available. In the current model, the designer has to go from the office to the production facilities to get this information. In my opinion, this is a wrong approach because the designers should have information on what kind of tools are available and what kind of features they have. The same applies to the Finnpower combi machines, as the designers do not necessarily know what tools are available and how to use them effectively. For example, a punched hole is considerably cheaper to produce than laser cut in which the holes are now cut crosswise in relation to these features. The company should therefore consider ways to harmonize this feature as well as to find the answer as to where the responsibility of the determining manufacturing methods is placed between the designer and the programming. Now the responsibility between designers and programming is unclear.

In programming, the risk of programmer-based errors is most obvious in connection to the use of the standard library. There may be cases where the product being programmed is similar to the standard product but some dimensions differ from the product being produced. This poses a high risk if the programmers use standard programs with nesting, without checking the similarity of the drawings. The programmer does not have the drawings of the product but the programming takes place on the .dxf file produced by the design department. The risk is to release a product not equivalent to the designed product to production. In such cases, the generated error is corrected in production, which creates a possible delay in production.

The company's product data management is currently organized with Windows explorer environment, which creates a possible risk for human-based errors that may cause disappearing of data. In the current model, the file may be deleted or replaced with another version, making the information disappear. Additionally, it may be possible that files are moved into the unwanted folder, making them difficult to be found, or from the server to the local workstation. In all cases, the risk of data loss is high. All this has been caused by the fact that there is no system for design data management, but Autodesk Vault PDM system is now being implemented. This system will eliminate the risk of information loss possible in the current system. In addition, the new PDM system will provide possibilities for version tracking now made based on Windows time stamps.

6.3 Revision management

Currently, the revision management in Poland is inadequate, to say the least. Now the new PDM system being implemented will offer facilities for revision management. Nevertheless, the revision management perspectives in the current design process have been clarified in this chapter in order to address any potential disadvantages.

The revision management of design data is currently the designers' responsibility. Revision of the drawings received from Finland is now manually inserted into the production plan .xls file. From this data, the designers can find the latest revisions for the product. In a typical case, the changes come from Finland to the logistics department when the design work has already begun. After that, the logistics department will inform the design department by sending a new drawing and a request to make changes to the designer via email. The situation is very difficult when comparing the changes of the product between Polish and Finnish drawings. In practice, the designer compares the previous and newer 2D drawings by overlapping them in order to detect differences. That creates a risk that the designer does not notice all the changes and an incorrect product is delivered to the customer.

The method of publishing design documents also constitutes a risk of releasing an incorrect revision to production. In the current situation, the designer publishes the finished product drawings to production. In practice, the designer prints the compound package of drawings, which is stored into a locker in production. In situations where the revision of the product has been changed and the drawings are already published, there is a risk that the old drawing is released to production. Publishing such a drawing may lead to a defective product or problems in production.

All the drawings produced for one item are managed by using the main document drawing called a production drawing. This drawing contains all the drawings that are required to manufacture the product. The files are imported into the document both from Microstation and Pro E. The situation is interesting because the data attached to this drawing is not connected to the previously produced parent drawing. If any part of this drawing is modified, the information will not be updated into the original parent file. The situation is the same the other way around, so there may be cases where the product of the main document is different to the manufactured product. If the document is to be used for the documentation of the final product, the company should find a solution in which the document would be composed of valid design data. In this case, the modifications of the main drawing should also be passed into the parent files.

6.4 Avoiding manual work

There are some manual work phases in the current design process, so it might be sensible to look for alternative solutions. These include the separation and marking of the cutting methods in the ERP system, the sorting of the finished design data in the production folders, and the compilation of a production drawing. The two latter aspects may be avoided with the new PDM system, which means that there is no need to use resources for sorting the product data. The new system would allow product-specific production drawings and documents to be compiled from a single information system without having to manually sort the design data.

As mentioned in section 6.1, a new laser machine will be added to increase the need for separating the parts in accordance with the machine base. At present, the designer has manually separated the parts that require programming or have to be cut by shearing with the guillotine. The programmable parts of the existing combi machines can be programmed with the same software due to the machine base. The new laser machine will require its own nesting software for programming, where only parts for this machine type can be programmed. The parts that require punching or forming features of the combi machine must be guided through the old machine base.

The designer executes the cutting separation by creating an .xls file that specifies the title, material, thickness, and quantity of each parts, which requires NC programming. The contents of the file are embedded in the ERP system. Based on this information, the logistics department compiles the order-based laser block that includes all parts that need to be programmed. With the new laser machine, it should be considered how the cutting of the parts would be prioritized. It is clear that the punched and formed parts will be programmed with the old machine base. The challenge in this situation is that the parts programmed to the old machines are not suitable for cutting with the new machine. Therefore, the machine should be chosen before programming.

In the future, it should be considered how the cutting methods could be exported into the ERP system without having the designers to manually compile a list of the parts. At the same time, it would be possible to find a solution for including the information on the used machine base into the production systems. One option would be to include a parameter in every part that would be automatically embedded in the ERP. The new CAD software may provide an opportunity to include such a parameter that would be transmitted as BOM data into the ERP by using the customized LinkIT add-ins. The task of production planning and calculations of the machine loads falls on the logistics department. According to the orders and the ERP data, the logistics department complies the laser block for the programming department where the machine base has already been taken into account.

The clearest and possibly the largest factor that contributes to the extra work is the grinding direction of the sheet metal parts. At present in nesting, each part will be rotated according to the grinding direction on the sheet, according to which the parts are rotated either in the 0°/180° or 90°/270° limits. This is done according to the grinding mark included in the .dxf data. Because of this constraint, each part is brought to the nest one by one.

The NC Express is a nesting software used with combi machines that would provide the opportunity for mass-drive importing with which the orientation is taken into account. This feature has not been utilized, since there was no information on the orientation of the parts. At the moment, the parts are placed in the .dxf file horizontally or vertically, and the same file may contain more than one part that can be freely oriented. Since the name of the file alone cannot determine as to how the part is oriented, each part must be brought to the nesting one by one and rotated on the sheet according to the grinding direction. In the future, the sheet metal parts could be placed horizontally on the sheet, so that the parts would always be in the same direction as others. Another option would be to include a parameter in the CAD software that could be embedded in the ERP and from it into the laser block file. In this case, parts with the same orientation could be imported automatically as mass driving.

The marking of the cutting parts is currently performed by the operator. The operator marks the cut sheet blanks according to the laser report so that the parts will not disappear between production stages. The new laser machine also has an option for marking the sheet metal parts with a laser, so it would be sensible to find out if this feature should be implemented. By avoiding the present labelling work, a piece could be released faster to the next stage of production. On the other hand, as mentioned earlier, the bending of the sheet metal parts usually forms a bottleneck in production. As a result, the faster release of the parts into production would not affect production efficiency. In any case, the advantage of the present marking is that each part is checked in accordance with the laser report as they are moved into trollies to wait for the next stage.

6.5 Other observations

In the programming department, the programmers tend to optimize the material utilization with small nests. This usually happens when the programmer received an urgent order as a result of missing parts, additions to an assembly in production, or incorrect products. In these cases, the programmer will get the order for the nesting of a small batch size. According to the practice, the use of material has been optimized by finding out what kind of waste is left behind. The programmer programs and nests the parts to determine dimensions for the needed sheet. After that, the programmer prints the nest on paper with the dimensions and asks for available material in the production. According to the programmer's dimensions, the guillotine operator will cut a suitable piece for nesting. In this case, the work input used to optimizing the process is greater than the benefit of it. Even when keeping in mind the continued need for production with smaller sheets, it would surely be the most sensible to nest the small batches with a full sheet size. After this the larger extra part could be stored for later use. The storage of the larger sheets is placed next to the guillotine from which material is selected for cutting rectangular sheet parts for production.

Bending-related observations point to the remote programmability of the press brakes that is not currently being utilized to the level it should be. The programmable NC press brakes are now operated manually based on the operators' experience and knowledge. Although programming for the machines is not performed by the designers, the operators have access to user-specific programs for standard bends.

In connection with the study, it became clear that the company has tested programming of bending in production a few years ago. In this case, the challenge was created by the differences between the designed sheet part and the actual part. The reason for this was the differences between the bending tables used in design software and in the NC programs. After the programming and nesting, the part did not match the size of the designed part. The designers' ability to choose a bending order that would be a prerequisite for programming was also challenging. In the current operating model, the operators decide the bending order by themselves.

If the bending were programmed in the design stage, it would be possible to avoid a constriction bottleneck. The advantage of programmed bending would be to bend a part one by one, in which the machine would automatically adjusts the correct parameters for each bends and the position of the backgauge. In this case, the bended part would be released faster to production compared to the current model. In this model, each part will be bended in sets where the parts are released only after all parts have been produced.

The largest obstacle to change seems to be the ability of the design to take into account the machine base used with bending. At present, designers use material-specific bending tables that do not take the machine into account. In addition, designers do not have the know-how on available tools and their capabilities. When the implementing into the new CAD environment is ready, it would be relevant to update the bending tables according to the production machines and tools. Once the new system has been implemented and the CAD design line aligned, the design could be extended to the CAM environment where the designer would be able to focus on product design from the manufacturability point of view.

7. CONCLUSION

The thesis studied the sheet metal process of the target company as well as the associated information flows. Based on the theory, a general view of the sheet metal process and related information elements was created. The theoretical study focused on the different work phases of the sheet metal process and looked into factors that interact with the NC process of the company. In addition to finding information, related factors should be taken into account. The mapping of the current sheet metal process of the company required examination of the current situation.

The present state of the sheet metal process was investigated through a qualitative case study in which the designers and programmers were interviewed. At the same time, a factory tour was taken and observations were collected concerning the production process. The collected data was transcribed and on the basis of it, a general view was generated on the sheet metal process of the company, which includes the key work phases and related information flows. These were illustrated with the production process flow charts on the key processes in which work phases and related information are associated. Then potential problems were investigated in connection to the information flows of the sheet metal process and recorded in the charts. The challenges identified have been presented according to the theme areas and potential development ideas have been suggested.

The target was to provide a general view of the current process with the related information flows, which succeeded moderately. The challenge was to achieve the targets set for the efficiency of data transfer and the process. Nevertheless, based on the survey, it was possible to locate the most important information flows in the NC process and to see how the new laser machine will affect the current process model. In addition to this, it was possible to suggest some development ideas.

At present, the information flows for sheet metal manufacturing of the company are very challenging to map due to extensive changes in the design system environment. The company is currently implementing a new design system and, additionally, the system for product data management. Taking this into account, the survey was a success, and the results of the thesis can be utilized in future studies. Based on this, any further studies can be directly focused on the potential problem areas.

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APPENDIX A: INTERVIEW QUESTIONS

Interview questions General information		1. interview	2. interview	3. interview
1.	What happens when you have received order from Finland and which are main work phases after that?		x	x
2.	How designing process goes forward and draw mind map/diagram where these steps are presented?	x	x	x
3.	What kind of systems are used in manufacturing e.g. CAx, ERP, PDM, etc.?		x	x
4.	What kind of information these systems provide and where is it used?		x	x
5.	Which process steps need to take into account in sheet metal designing? (design, programming)		x	x
6.	Now there are five systems which work together: Microstation, ProEngineer, Inventor, (Vault), NC-Express and TruTops; How these five systems play role in designing and where it is needed to use these?		x	x
7.	What is the significance of Finnish design in Poland? Is there something which could be done by the other ways? For example some detail which increase the manufacturing costs in sheet metal process.		x	
8.	Did you have any situation where the part is made again caused by Finnish design mistake? Example some included data has been presented incoherently in the drawings. How often this happens?		x	
9.	When factory has received a new order, How they get this information and how the data is registered into production system?		x	x
10.	What happens if you will make a new revision of the product? How this is noticed and are you registered new revision to somewhere that anyone could receive this information? Where?	x	x	x
11.	Are the manufactured products separated with an alternative manufacture methods e.g. laser, punch, and other cutting		x	x

	methods? Which work phases are required from view of sheet metal processing?			
12.	Do you know production times for the workpieces and where it is based? Is it based on empirical knowledge or monitored from each processing phases? Is there some database where it could be stored?		x	x
13.	If we focus on sheet metal processing. What kind of designing, programming and sheet processing data have been collected to ERP system?		x	x
14.	When the product will be taken into production? Does it take into account the time which is spent on manufacturing?		x	x
15.	Are there required sheet metal materials in stock? How much material will be needed and what is the proportion of waste material? Where this information is stored?		x	x
16.	When the parts are nested, is the knowledge of actual material consumption and generated waste material reverted into the database? Consumption from unfolding drawings (BOM) and waste material info from nesting?		x	x
17.	Do you have any statistics about production capacity of machines? When is it able to add production to the lasers without over loading?		x	x
Technical design				
	Design			
18.	What is the real challenge when you start to design products according to Finnish request?	x	x	
19.	How Finnish model may affect to designing that production model can be able to manufacture?	x	x	
20.	How empirical shapes are taken into account on unfolding? Are these designing tasks based on human knowledge or do you have library for these special shapes? For example corners where shape is different on unfolded drawing vs standard based unfolding.	x		
21.	How designers have noticed manufacturing knowledge of bending tools?	x	x	
22.	How you make sure that the product can be manufactured?	x		

23.	What kind of data have included in unfolded drawings for bending machines?	x		
24.	Which are the requirements of programming when designing a new product?	x		x
25.	If programming team have some technical issues with a model. How the model returns back to the designers and what kind of information have included?	x		x
26.	How many types of drawings you need to do for production e.g. assembly drawings, unfolded drawings etc.? Is each of these made separately or generated from the parent model?	x		
27.	What kind of drawing is shared for programming team and is it unfolded drawing or reduced version?	x		x
28.	What are the challenges with information flow between production and designing team? If there is some issues in production. Are you able to get information that you could develop and notice this afterwards?	x		
29.	Do you have a database or library where you can get the needed technical parameters as material thickness, standard shapes, etc.? Or is it only based on designer's knowledge?	x		
30.	How the revision management have been organized and what are the challenges?	x		x
31.	How grain direction is observed in designing?	x		
CAD				
32.	How the following conversion have been done: 3D modelling – unfolding – Database (sheet metal parts)?	x		
33.	What is Autodesk Invertor's role vs. Pro Engineer at the moment?	x		
34.	How it is able to repair empirical shapes as corners etc. to unfolding drawings? Have your CAD software some tools for that kind of use?	x		
35.	Export file format have been DXF, what about SAT, STEP, IGES?	x		x
36.	TruTops unfold supports many import formats, why we don't use this feature? Do you have any ideas why or is it question for programming team? 3d -> unfolding -> nesting	x		x

Programming				
Programming				
37. What are the phases of NC programming and how it goes step by step? Draw mind map/diagram			x	
38. Is there some information available for these phases and do you have a guide/handbook or design library where could get this information?			x	
39. When designers have done their work. How you get information that NC team can start programming?			x	
40. When programming start, do you confirm that the model revision is latest and how?			x	
41. You have database for production planning where starting of programming is registered. Do you add this information and approximation when it is ready? Or is it set by others and indicate the deadline when it needs to be ready?			x	
42. How programmer separate the parts by material thickness. Do you check every parts one by one, this is 1,5 mm and this 2,5 mm? Are these parts added to folder structure where each thickness have own folder or are these files named logically?			x	
43. Do you have some protocol for nesting planning? Is it that the production planning system gives guide what to do and information which sheets are available in stock?			x	
44. Have each sheet only parts from one furniture or is the sheet usage optimized by using parts also from the other items?			x	
45. How current working method take notice of punching tools? Are these parts also included to the same sheet?			x	
46. How you try to minimize the material waste?			x	
47. How gain direction is take into account on programming?			x	
48. How often laser's test drive is necessary or need to do some test parts? Do you have any possibilities to replace these by simulation?			x	
49. How programmer register knowledge of needed materials. Is real material consumption returned back to production planning or other system?			x	

50.	In the future it will be important to know which parts are going to laser or punch machine, because of machine base. How it is already attended?			x
51.	Is there something what designers could be do better, making nesting more easily?			x
52.	How you get information of production issues. Comes this information straight from the production line or agency of designers?			x
53.	When NC programs are ready and storage to wait production, how these are picked up to the machines?			x
	Nesting software			
54.	What is used import file format now and why? Have you tried any alternative formats with nesting?			x
55.	Unfolding is now done with CAD software. Could that be able to do under NC Express or TruTops?			x
56.	Is it able to move already programmed part between two different machine types? In spite of that punch parts priority will be on NC Express in the future. Have you thought anything else?			x
57.	Now you have TruTops training with Trumpf behind. Have TruTops some new features which could help us with nesting?			x
58.	Could we start 3D importing with TruTops?			x
59.	If we start unfolding the parts with TruTops. Could bending tool library be modified that it would automatically recognize empirical shapes? For example table corners where material could be cut as now and we will keep already learned manufacturing methods.			x
60.	If unfolding is made with nesting software, could this program also share unfolding drawings to production? Drawing which allows working with the bending machines.			x
61.	How nesting is automated now and how we could optimize it more?			x
62.	Big challenge will be with grain of sheet metal. Is it able to take account in TruTops? Can you feed some parameters which could affect how the part can be rotated? Some add-ins might be needed for managing grain direction?			x

63.	What about material management, how we choose a right sheet size? How it is optimized or not? Is it automated process on nesting software or have been done manually?			x
	Production			
	Laser cutting			
64.	How Finnpower punch and laser machines are operated? What kind of challenges did you have with these machines? What you waiting when Trumpf laser coming soon?		x	x
65.	How cut parts have been arranged and numbered that those parts will not lost before next phase. How this delivery to next working platform have carried?		x	x
66.	Have we knowledge what is used working time on each working steps? What about availability of machines or reality load on machines, is that data available?		x	x
67.	How often there is some delay on production, caused by bad manufactured parts?		x	x
	Punching			
68.	What is contribution of punching parts and how these are separated from the other cutting parts?	x	x	x
69.	Could we set priority for these parts to Finnpower and include information of machine base to somewhere? Or how we could know is the part going to program with NC Express or TruTops?		x	x
	Bending			
70.	Bending with machines happens now manually. How the parts keep tolerance and what is allowed margin on the bended parts?		x	
71.	Have you been in situation where designed parts are not able to bend with available bending tools?	x	x	
72.	Do you have design library which include our bending tools? It could be way to bypass that kind of designing	x	x	
73.	Have you faced situation where bended part have been lost?		x	
	Final processing			

74.	Is there other working phases which affect straight to the sheet metal process as designing, cutting or bending? For example table corners need manual work where radius is hammered, is there any this kind of phases?	x	x	x
		25	**31**	**55**

APPENDIX B: PROCESS FLOW CHART – CAD DESIGN PHASE

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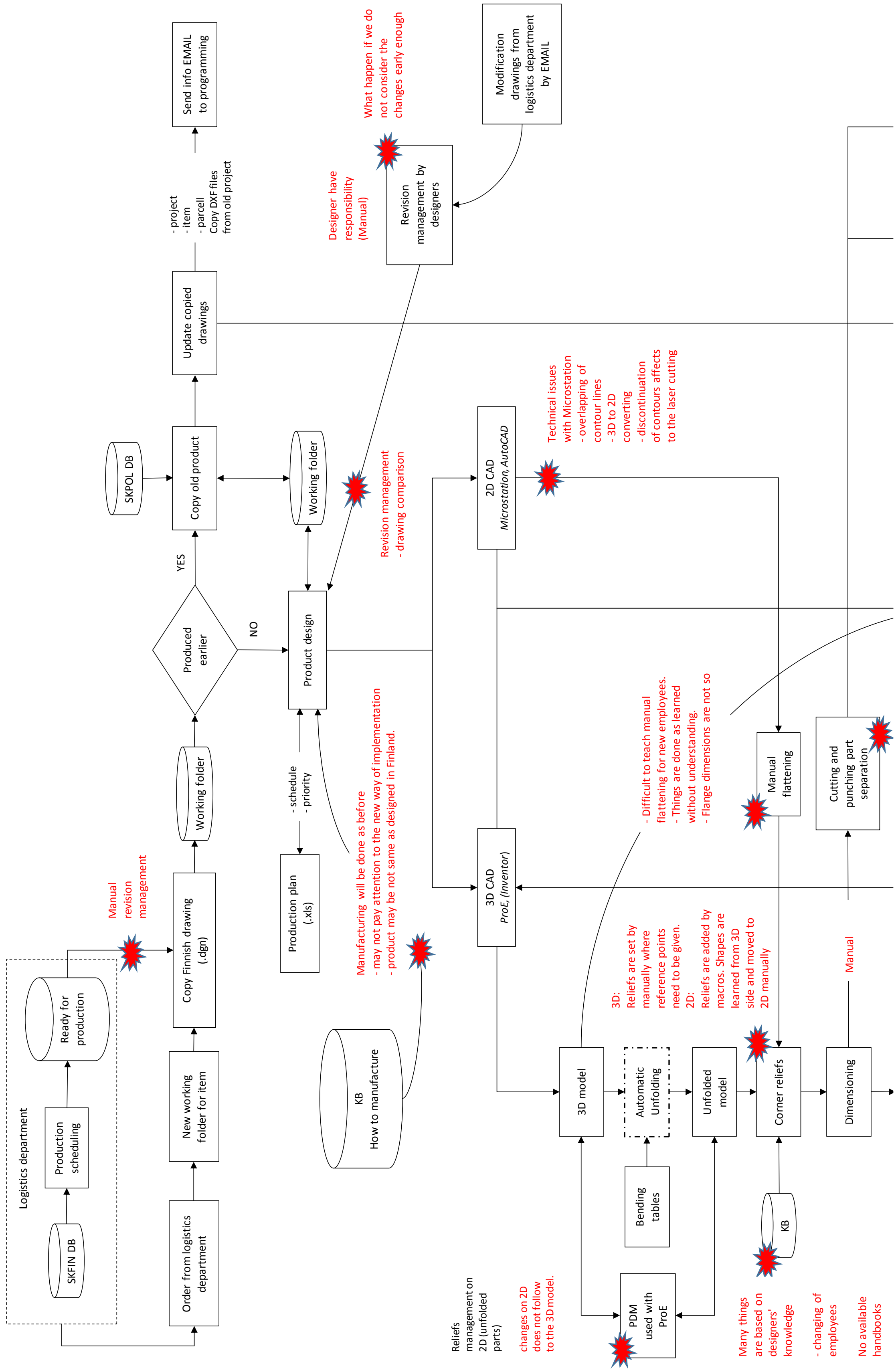

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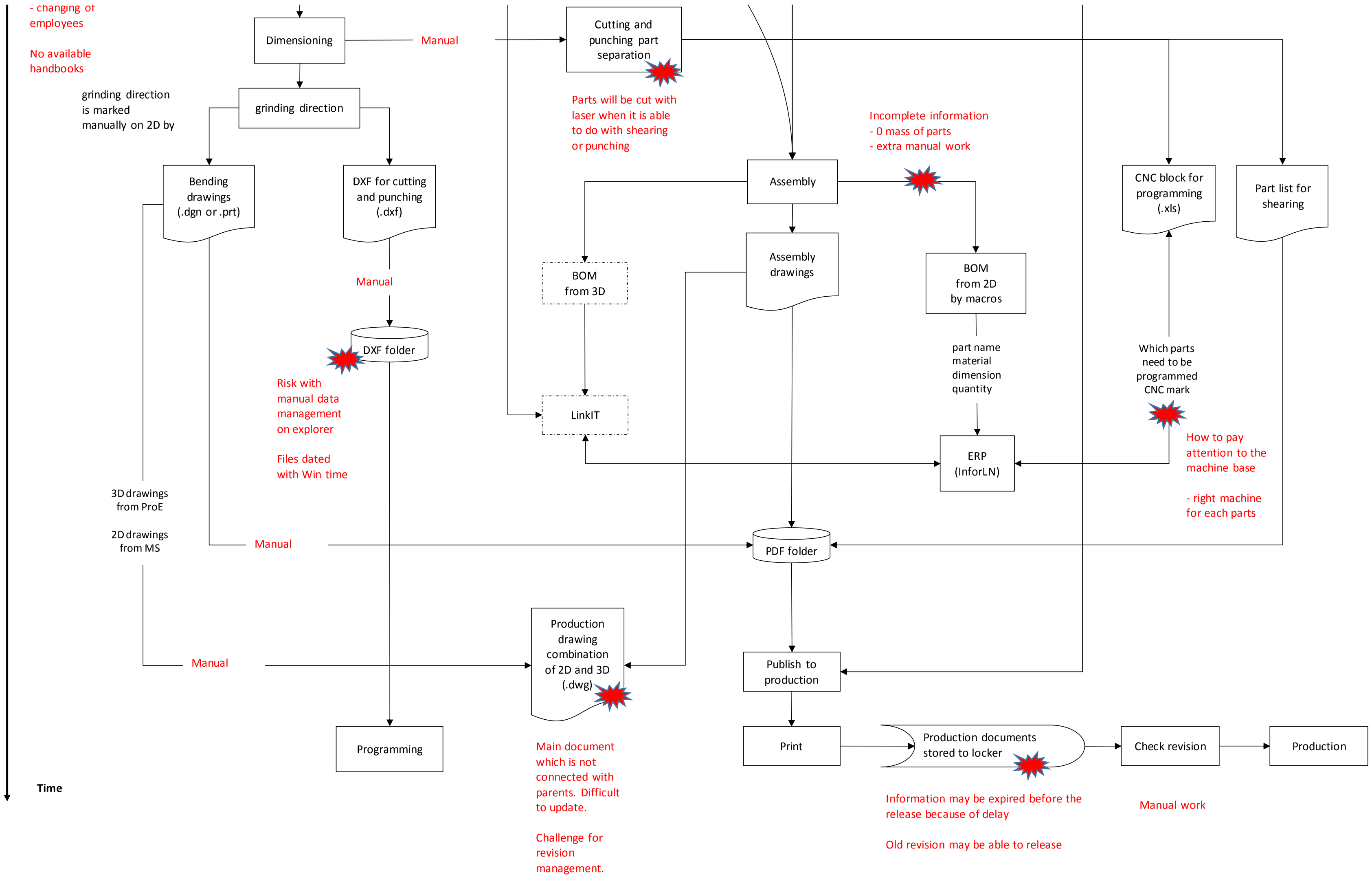
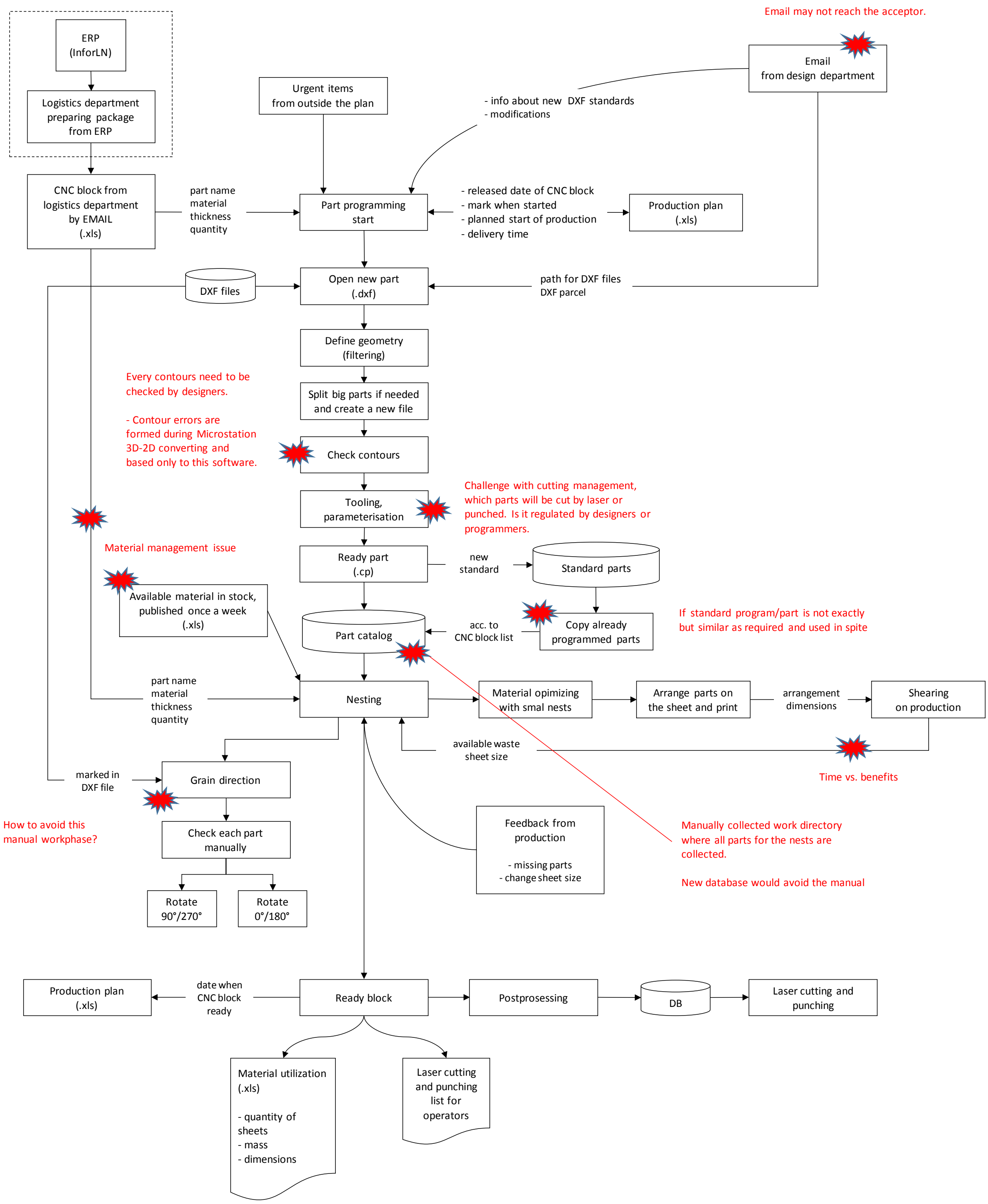
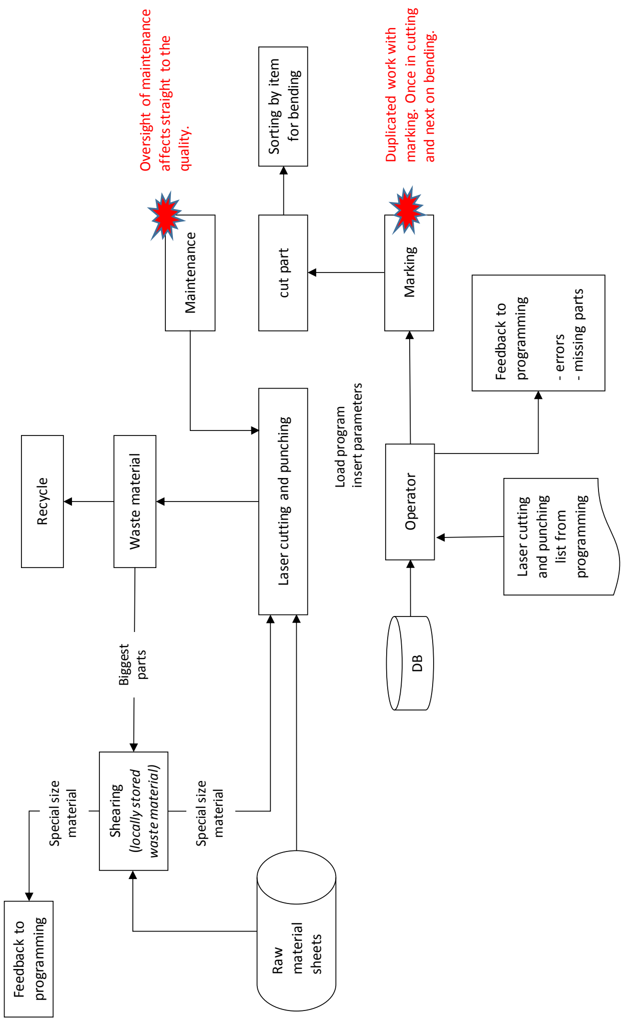

- changing of employees
No available handbooks
grinding direction is marked manually on 2D by
Dimensioning
Manual
grinding direction
Bending drawings (.dgn or .prt)
DXF for cutting and punching (.dxf)
Manual
DXF folder
Risk with manual data management on explorer
Files dated with Win time
3D drawings from ProE
2D drawings from MS
Manual
Manual
Programming
Cutting and punching part separation
Parts will be cut with laser when it is able to do with shearing or punching
BOM from 3D
LinkIT
Production drawing combination of 2D and 3D (.dwg)
Main document which is not connected with parents. Difficult to update.
Challenge for revision management.
Assembly
Assembly drawings
Incomplete information
- 0 mass of parts
- extra manual work
BOM from 2D by macros
part name
material
dimension
quantity
ERP (InforLN)
PDF folder
Publish to production
Print
Production documents stored to locker
Information may be expired before the release because of delay
Old revision may be able to release
CNC block for programming (.xls)
Part list for shearing
Which parts need to be programmed CNC mark
How to pay attention to the machine base
- right machine for each parts
Check revision
Production
Manual work
Time

APPENDIX C: PROCESS FLOW CHART – PART PROGRAMMING AND NESTING PHASE



APPENDIX D: PROCESS FLOW CHART – LASER CUTTING, PUNCHING AND SHEARING



APPENDIX E: PROCESS FLOW CHART – BENDING